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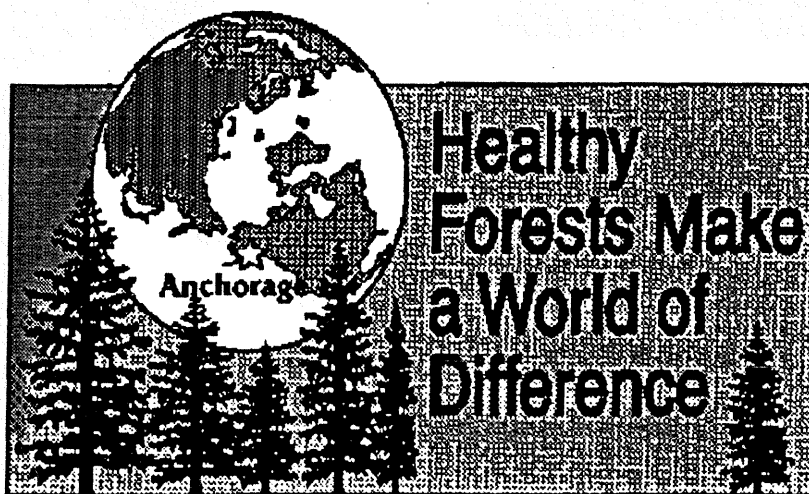
# FOREST HEALTH PROTECTION *SPECIAL REPORT*

Forest Service

Alaska  
Region



## *Reforestation and Vegetation In Central Alaska*



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# **REFORESTATION AND VEGETATION IN CENTRAL ALASKA**

**By**  
**Michael Newton and Elizabeth C. Cole**  
**Oregon State University Department of Forest Science**  
**Corvallis, OR 97331**

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## EXECUTIVE SUMMARY

The three following papers summarize nine years of research by Oregon State University, Department of Forest Science relating to the principal technical obstacles to artificial regeneration in south-central and interior Alaska. The key elements include 1) determination of severity of plant competition and consequences of not weeding in the first five years of spruce plantations, 2) comparisons of methods of controlling competition, and 3) evaluation of environmental impacts of the various methods of vegetation control. We also address preliminary findings on importance of the size of planting stock after various forms of mechanical and chemical site preparation.

Plant competition in the forms of grass, fireweed, aspen, and other overtopping species severely reduces growth and survival of interior white spruce. Allowing vegetation to become established before planting leads to sharply poorer post-planting performance expressed as volume growth. Trees planted in established cover that is chemically controlled grow significantly more slowly than when planted in new clearcuts receiving apparently analogous degree of control. That is, it takes less cover to slow spruce growth in a 3-year-old clearcut than in a new unit when all other conditions are the same. Seedlings grow twice as fast in the new clearcut than the old in the same ranges of cover. If the clearcut is freshly burned, seedlings grew twice as rapidly as in the new, unburned soil, cover for cover. In all types of harvest unit, speed of overcoming white spruce "planting check" was positively related to degree of freedom from competing cover. With competition-free plantings, height growth was approaching the same rate for all three types of unit (burned, new clearcut, 3-year-old cut), but methods of weeding other than annual chemical maintenance varied in efficacy according to weed cover at the time of planting; more cover reduced efficacy, in general. This was observed near Fairbanks and also at Ft. Richardson. Patterns were very consistent for the two sites and different years of planting.

Mortality of planted spruce was affected principally by two factors. Overtopping was a major cause, but often required several years to cause death. Very early severe freezing (15° Sept. 8, 1993) caused mortality on Fairbanks experiments that were nearly

competition-free, and were late-flushing. That was an extreme event, repetition of which is very rare, hence we discount freezing as a major risk of weeding.

Paper birch plantings responded to competition much as did white spruce. Unlike spruce, browsing by moose at Ft. Richardson all but eliminated differences in height for various levels of competition, but weed-free birch developed much more stem volume and biomass. Freezing damage is a major cause of mortality in all treatments on sites with cold-air drainage.

When comparisons of planting stock types were done after four different methods of site preparation, plug-1 transplants were 2-4 times as large in year 3 as either of two commercial 1-0 plug types on sites treated with glyphosate plus hexazinone before planting. This site prep method was significantly more effective than spot spraying, mechanical clearing, or fresh logging alone. In all methods of site preparation, the plug-1's grew 2-4 times faster in terms of absolute growth than other stock types by year 3.

Efficacy of methods for controlling vegetation to meet seedling needs is very similar to findings in the Douglas-fir region. Glyphosate, imazapyr, and triclopyr may be used at rates that cause negligible harm to spruce, yet will kill most herbs and deciduous shrubs at chemical cost of <\$50/ac plus application. Glyphosate is effective on most of Alaska's competitors for <\$30/ac alone, but has no residual effect. Hand scalping and hand brushing may provide for conifer establishment in grass or alder cover, but hand scalping of grass was difficult. Mechanical methods are feasible for favoring moose browse. Details of all treatments are given.

Environmental impacts of chemical methods were evaluated in terms of persistence and mobility of chemical residues in vegetation and soils. Residues in vegetation were completely dissipated for glyphosate, imazapyr, hexazinone and triclopyr within one year on a coastal site (Windy Bay), and triclopyr persisted slightly longer at low levels near Fairbanks. Mobility in soil was low, with no more than 30% of an initial deposit in the surface soil moving below 6". Persistence in Alaska was comparable to growing season environments in the lower 48 states. Half-lives in the summer environments range from estimates of 25 to 120 days for the four products, with hexazinone the only one over

about 50 days. No dissipation occurred or was expected in winter. All products were non-detectable by 410 days after treatment in all locations.

All four products evaluated are low in toxicity, and difficult or impossible to dislodge from the field environment unless freshly treated vegetation is contacted. Vegetation residues were all within the range of concentration producing no observable effects in test animals. Hexazinone moved off-site in water on large plots treated for evaluation of worst-case conditions. Whereas 7% of the applied hexazinone appeared to have left these sites under intensive rain events, concentrations are unlikely to reach detectable quantities in fish-bearing streams in basins with 5% of the entire basin receiving treatment.

Mechanical or manual controls of vegetation have inherently higher environmental impacts than herbicides in terms of total energy use, total chemical use and potential for causing stream pollution with silt or fuel. They also seldom provide extended control of vegetation in sufficient degrees to enhance over-all reforestation efforts at acceptable costs.

### ACKNOWLEDGEMENTS

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# REFORESTATION AND VEGETATION MANAGEMENT IN CENTRAL ALASKA

## I. COMPETITION AND THE NEED FOR VEGETATION MANAGEMENT

Elizabeth C. Cole and Michael Newton<sup>1</sup>

### INTRODUCTION

Unprecedented levels of bark beetle infestations and concurrent timber salvage operations have created a major need for forest rehabilitation in the white, Sitka, and Lutz spruce forests of Alaska. The commercially important spruce and birch forests are concentrated in low elevations on the Kenai Peninsula, Susitna River basin, Copper River basin and in the Yukon/Tanana uplands and floodplains north of the Alaska Range. Many of these sites are covered with medium- to fine-textured soils of excellent fertility. Despite the cold to frigid winters, growing conditions in summer are good. Summer rains and very long days provide for productive potential consistent with sustainable forest management. However, the same productive potential leads to heavy covers of herbs, shrubs, and hardwoods that threaten regeneration of spruce (Youngblood 1995).

Natural regeneration of white and Lutz spruce is hampered by the conditions of the current beetle epidemics. Characteristic of beetle attacks, dominant spruce are killed early in the outbreak, causing a decrease in seed production. Over a period of several years, increasing spruce mortality stops seed production altogether, and meanwhile opens canopies so as to stimulate growth of Sitka or green alders, elderberry, salmonberry, devilsclub, and other shrubs, and grass (*Calamagrostis canadensis*) (Holsten et al. 1995). Thus, as seedfall decreases, the probability of a favorable environment for germination declines, and natural regeneration virtually ceases.

The onset of understory cover complicates post-salvage reforestation operations. Grass and shrubs grow much more rapidly than conifers in the seedling stage. Small seedlings characteristic of production container nurseries are in an inferior competitive position, and are also subject to the physical impact of collapsing herbage in fall. Thus, both seedling characteristics and vegetation are involved in reforestation success.

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<sup>1</sup> Senior Research Assistant and Professor, Department of Forest Science, Oregon State University, Corvallis, OR 97331

This paper outlines the findings from a series of planting experiments in which we have documented seedling growth and survival for 3 to 5 years. These experiments have also determined which competitive conditions are associated with levels of seedling growth, and what treatments are effective manipulations of seedling environment.

Our experiments are established in two areas. One is at the Bonanza Creek Experimental Forest, about 20 miles west of Fairbanks. The other is at Fort Richardson, 10 miles northeast of Anchorage. Selection of these sites provided ranges of conditions relevant to much of the commercial range of white spruce.

The array of competitive conditions formed in these experiments was produced by application of herbicides in various ways. The experiments from which the treatments were derived are described in Section II of this series of reports. Section III describes additional experiments that inquired into the persistence and mobility of herbicide residues in Alaska, and provides perspective on comparative impacts of chemical versus non-chemical choices for vegetation management.

## METHODS

Experiments in both sites attempted to provide information of several kinds. Specifically, we were testing the hypothesis that seedling growth is inversely related to total cover and to overtopping. The corollary of this is that seedlings respond positively to treatments to reduce competition in proportion to the cover remaining after treatment. The second major hypothesis is that seedling response to cover and overtopping is the same whether seedlings are planted immediately after clearcutting vs. being planted three years after clearing, but with the same degree of vegetation control.

Seedlings in all experiments have been measured each fall for root collar diameter, height, and height increment. Measures of cover by species groups and overtopping were recorded at each seedling. Thus we are able to evaluate both competition and treatments to control it.

### Bonanza Creek experiments

Competition studies were established at Bonanza Creek in spring, 1991, and have now had five growing seasons of evaluation. These experiments included a broadcast burn treatment on a recent clearcut in addition to standard clearcuts newly installed and three years since harvest. All three units were cut following buildup of *Ips* beetles after the nearby 1983 Rosie Creek fire.

All clearcuts were on excellent spruce sites on south-facing slopes of 10 - 20 percent. Soils are deep loess. All stands had a component of aspen; hence, suckers were prevalent on much of each site. Besides aspen, *Calamagrostis* was present and expanding on both recent clearcuts, and was very dense on the 3-year-old clearcut.

On each clearcut, we established 18 plots 40 x 50 feet in size and planted them with 1-0 plug seedlings from the Alaska State Nursery, Eagle River. Seedlings were overwintered in a weed-free and fertilized bed located near the burned unit. Seedlings were planted at a 10 x 10-foot spacing with planting bars or hoedads. Each plot received one of six vegetation control treatments in a completely randomized fashion, with treatments as follows:

1. No further treatment—Untreated control.
2. Site preparation the previous fall with a mixture of glyphosate and hexazinone at 1.1 lbs and 1.5 lbs/ac, respectively (site prep).
3. Post-planting release with a broadcast application of hexazinone at 1.5 lbs a.i./ac (Year-1 release).
4. Year-2 release same as treatment 3 except delayed one year.
5. Year 1 and 2 release same as treatment 3 except applied in both years.
6. Site preparation the previous fall with glyphosate at 1.1 lbs ae/ac plus annual directed application with glyphosate (weed-free).

Seedlings growing without weeding were generally surrounded by almost total cover; overtopping occurred on over half the seedlings. The various treatments led to an array of competitive conditions encompassing the range expected in normal reforestation, including nearly bare ground apart from horsetail (*Equisetum* spp.) cover that was not especially responsive to herbicides.

## **Fort Richardson experiments**

### ***Competition study***

We selected these sites at Fort Richardson representing clearcuts zero and three years old, and also a site previously cleared with a Hydro-Axe to enhance moose browse. The two clearcuts had well-established grass cover owing to the open canopy of the preceding birch forest. The older clearcut and Hydro-Axe clearing also had considerable cover of aspen suckers.

In each clearing we established 8 plots in two blocks of four, but 80 x 50 feet in size. In each were planted 8 rows of 10 seedlings each at a 5 x 10 spacing, half white spruce plugs and half paper birch wildling seedlings dug up locally. All seedlings were planted in spring 1992, and measurements have been recorded for four growing seasons.

Treatments reflected choices after evaluating the Bonanza Creek experiments for a year. Four treatments were selected as follows:

1. No further treatment (untreated control).
2. Site prep. Hexazinone plus glyphosate as at Bonanza Creek applied the fall before planting.
3. Year-1 release. Application of 1.5 lb/ac hexazinone ULW diluted in KCl 0-0-60 fertilizer for distribution.
4. Weed-free for five years, as at Bonanza Creek.

We selected the granular hexazinone to avoid damage to container seedlings and also to provide season-long weed control. Spring rains, however, failed to materialize, and the hexazinone did not reach the roots until too late to affect control. Thus, this treatment is similar in appearance to the control, although the grass did decrease in patches in a way that influenced results.

### ***Mature forest conversion***

We augmented the competition studies at Fort Richardson with evaluation of strategies for converting senescent birch/spruce forests into managed ecosystems. These experiments included not only re-evaluation of normal planting stock after conversion and various weeding methods, but also comparative analyses of various planting stock types and species. Multiple-use

management in this area could include production of high-quality moose browse (willow sprouts), paper birch, and spruce. We designed vegetation management strategies on newly harvested sites that would lead to successful establishment of mixed species.

We installed the experiments in two 400- x 800-foot clearings on nearly level terrain. Clearing was done with a Hydro-Axe feller-buncher. Yarding was done with a D-7 tractor, with no attempt to avoid surface disturbance. The same tractor was also used for mechanical scarification in one site preparation treatment.

Each clearcut was divided in half, and in each half was established a block of four 150- x 150-foot plots ( $\cong$  half-acre). Each plot received one of four vegetation treatments, as follows:

1. No treatment other than harvesting (untreated control).
2. Chemical site prep, in which 1.5 lbs each of glyphosate and hexazinone were applied together a week prior to logging in late August.
3. Strip spraying with 1.5 lbs/ac hexazinone in 5-foot bands applied right before spring planting.
4. Mechanical scarification with straight blade with a goal of 50 percent mineral soil.

In spring 1993, following clearing, the plots were planted with the following stock types:

1. Alaska State Nursery at Eagle River plug spruce
2. Spruce plugs from Dean's Creek Nursery, Florence, OR (Alaska seed source)
3. Plug-1 spruce seedlings grown on site (plugs raised in AK State Nursery, Eagle River)
4. Willow rooted cuttings
5. Paper birch 1.5-0 plugs from Eagle River
6. Plug-2 spruce grown on site (planted 1994)

Stock types 1, 3, and 5 were planted in triplicate rows of ten seedlings in each plot. Owing to seedling shortages, Dean Creek plugs were planted in two rows of seven; willows were planted in three rows of eight. Plug-2s were planted a year after the remainder in only the chemical site prep and untreated plots because others had grown to look like controls. They were planted in 3 rows of 12 each.

## RESULTS

### Bonanza Creek

Fifth-year measurements demonstrated several major findings:

1. Without substantial freedom from competition, all stock types of spruce seedlings tended to decrease in growth rate for two or more years after planting, followed by very slow increase.
2. Timing of onset of spruce growth acceleration was related to level of competition, hence treatment.
3. Rate of spruce growth over the five-year evaluation period was strongly and inversely correlated with competition.
4. Complete freedom from competition through year 3 stimulated second flushing (lammas growth) that rendered spruce seedlings susceptible to extreme freezing conditions that occurred in early September of year 3.
5. Competition was more severe in 3-year-old clearcuts than in recently disturbed areas. Competitive effects of a given level of cover in 3-year-old clearcuts were greater than those of equal cover in a new clearcut.
6. Most rapid growth of spruce followed burning as a site prep with follow-up weeding.

Height-growth generally decreased in the first two years at all sites if significant first-year competition occurred (Figure 1.1). However, in the burn, some treatments applied in the first year resulted in steady or increasing height-growth by year 2 and substantial acceleration in year 3. Year 2 Release did not exceed first-year height-growth until year 4, and controls substantially exceeded first-year growth only in year 5.

The new clearcut showed only the site prep treatments as having accelerated height-growth by year 2 and seedlings of this treatment were somewhat damaged by a September 8, 1993 freeze, as were those of the weed-free. In the old clearcut, all seedlings decreased in height-growth rate until Year 4.

Overall, we observed that "planting check" in high-latitude white spruce can be reduced with a treatment that removes competition, and perhaps warms the soil. Under rare circumstances,

treatments successful in overcoming planting check led to increased risk of mortality from early freezing weather (Figure 1.2).

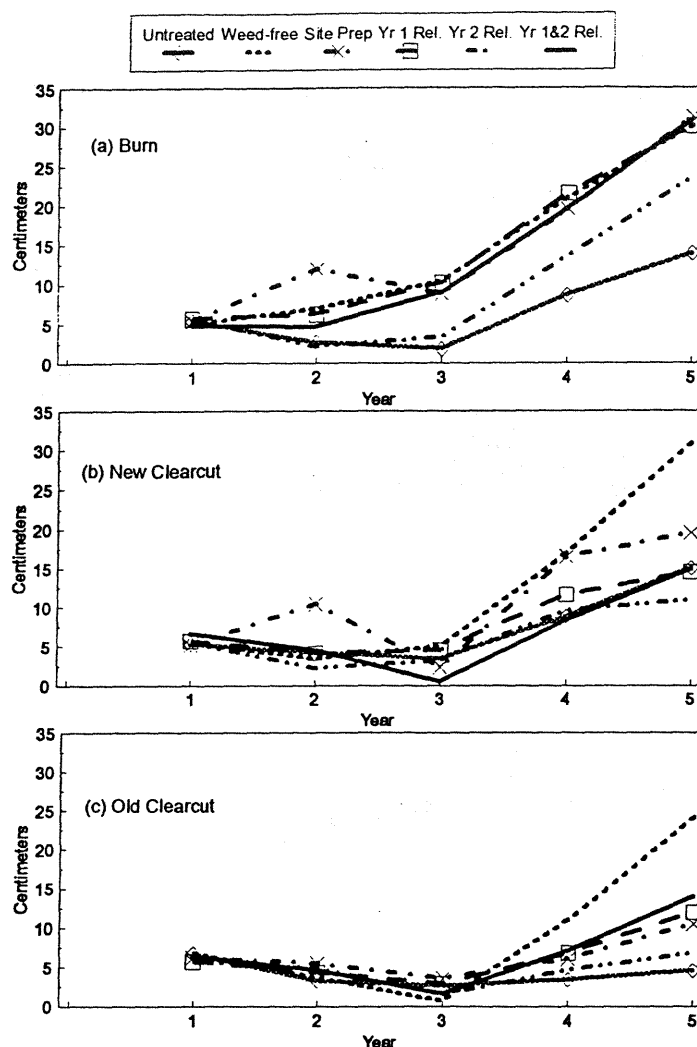


Figure 1.1 Annual height growth for different treatments and sites for Bonanza Creek Competition Study

Responsiveness of spruce seedlings to overtopping differed among clearcut ages and between burned and unburned fresh clearcuts (Figure 1.3). Between zero and 100 percent cumulative overtopping, as measured by cover within a 60-degree angle conical projection above the seedling summed for five years, there was a nearly linear decrease in stem volume growth. In this computation, note that a sum of 100 percent over 5 years is only 20 percent per year average, yet it accounts for major losses in growth, especially on the most favorable sites.

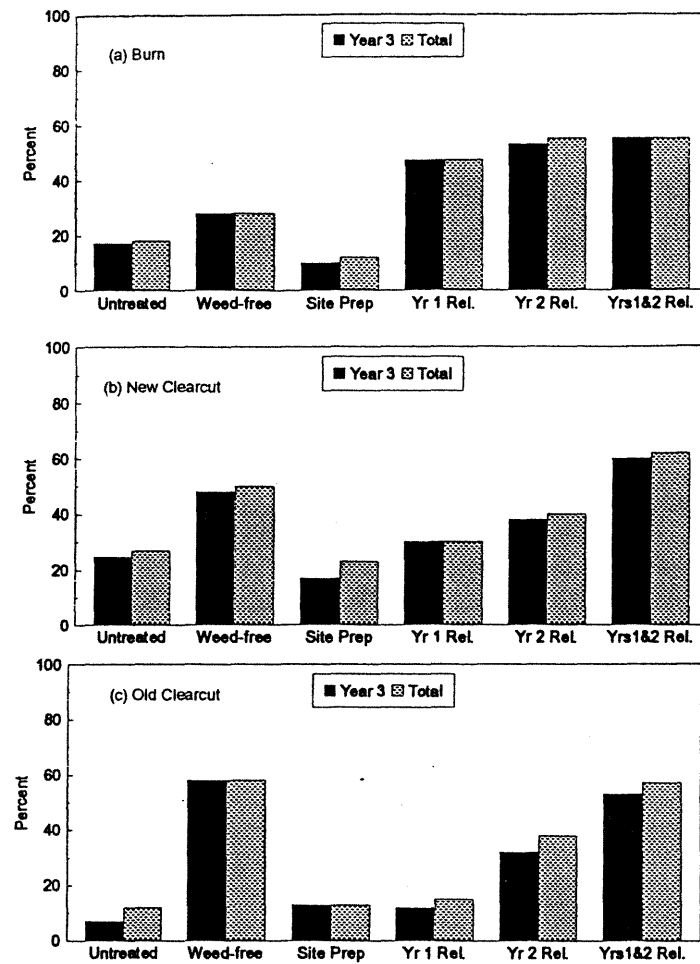


Figure 1.2 Percent mortality year 3 and over all five years (total) for Bonanza Creek Competition Study.

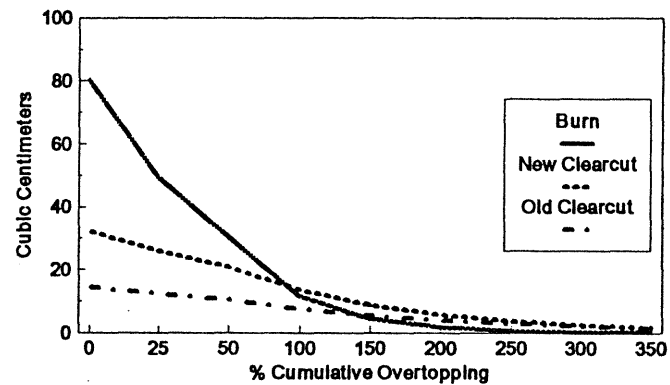


Figure 1.3. Stem volume/seedling in year 5 regressed against percent cumulative overtopping for three sites Bonanza Creek Competition Study.



Stem volume and volume growth are most closely related to development of leaf area, hence future growth. Figures 1.4a, b, and c illustrate that both treatments, sites and their interactions have very large effects on spruce seedlings. On the old clearcut (Figure 1.4c), only the weed-free treatment succeeded in providing reasonable growth. Weed-free provided by far the best growth also on the new clearcut, but site prep and Year 1 and 2 release also provided modest, (non-significant) improvement over the control (Figure 1.4b). However, the burn site prep effectively

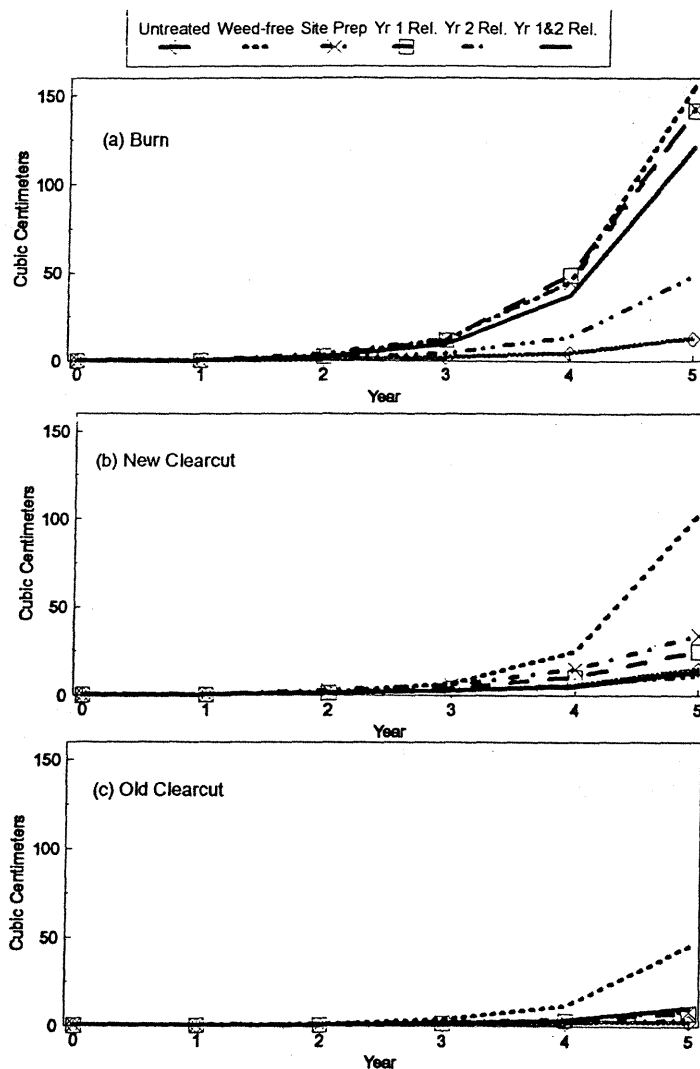


Figure 1.4. Stem volume/seedling for different treatments and sites for Bonanza Creek Competition Study.

removed several early successional competitors, and weed-free, site prep, Year 1 release, and Year 1 and 2 release all provided excellent results. Year 1 release and site-prep were identical. Figure 1.5 compares the three site conditions, the two most effective vegetation treatments, and the untreated plots. Of special note is the exceedingly poor growth on the site that had established vegetation prior to planting.

The above findings, especially as shown in Figures 1.4a, b, and c, demonstrate that white spruce is capable of excellent relative growth rates. Once these seedlings were in the ground for 1-3 years on a well-prepared site, volume tripled each year. This rate of acceleration is comparable to that of Douglas-fir in the Pacific Northwest except that more time (by about 2 years) may be needed to achieve that rate owing to planting check. However, on an average site, with even light competition, spruce is delayed more than five years in reaching a doubling of volume and foliage per year.

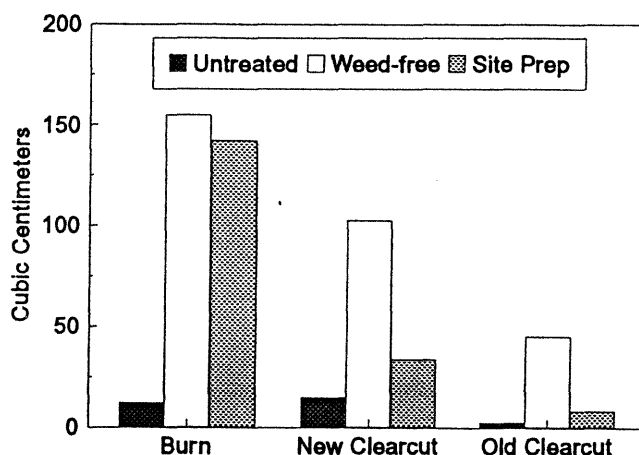


Figure 1.5. Stem volume/seedling in year 5 for three treatments Bonanza Creek Competition Study.

## Fort Richardson

### *Competition study*

Growth data from these experiments provide responses for only four choices of treatment, but give analogous data for spruce and paper birch, based on fourth-year observations. Spruce seedlings responded to analogous treatments at Fort Richardson albeit with a tendency for all seedlings to grow faster than their northern counterparts despite the apparently poorer site.

Figure 1.6 illustrates the tendency for height-growth to decrease during the first two years, then increase with favorable weed conditions. As at Bonanza Creek, the new clearcut (Firewood) showed less "check" tendency than the older clearcuts (Davis and Bulldog sites), and treatments producing low levels of cover provided the greatest degree of acceleration.

Spruce seedlings responded to cumulative cover much as did those at Bonanza Creek through Year 4 (Figure 1.7) in terms of volume. Figures 1.8a, b, and c again illustrate the ability of white spruce to begin annual tripling of stem volume by the fourth year, but that such increases are non-existent with intense competition. Even the "release" treatment, which scarcely produced visible effects on herb cover, showed a degree (non-significant) of improvement over controls on all sites (Figure. 1.9). This treatment was so variable in its effects that one can only use the results for

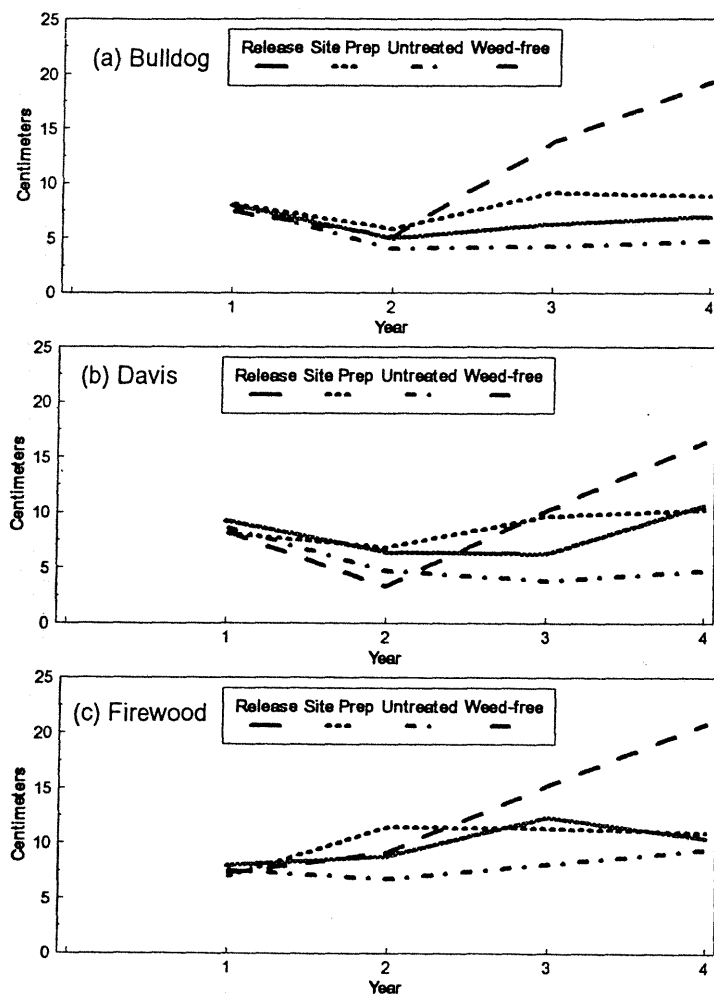


Figure 1.6. Annual height growth for different treatments and sites Fort Richardson Competition Study.

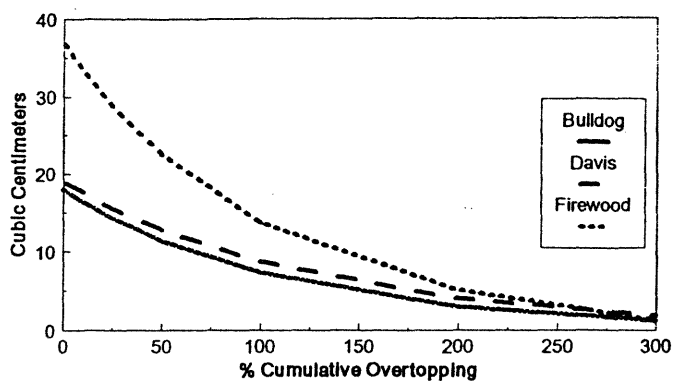


Figure 1.7. Relationship between stem volume/seedling in year 4 and cumulative overtopping for Fort Richardson Competition Study.

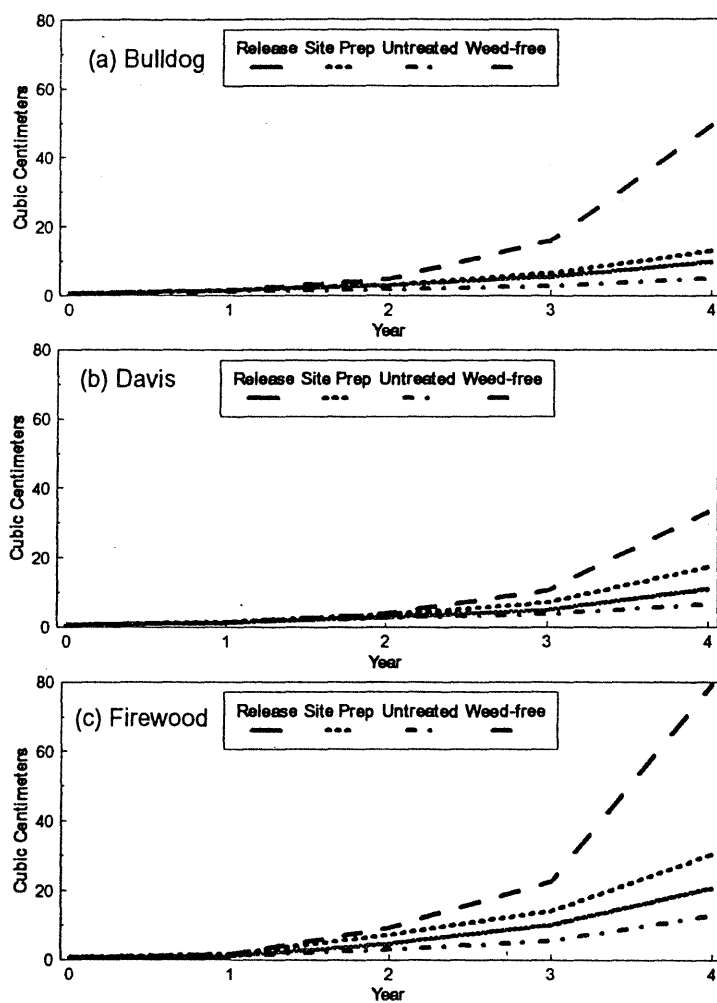


Figure 1.8 Stem volume/seedling for different treatments and sites Fort Richardson Competition Study.

evaluation of specific competition on individual trees. Although on average, response amounted to about a 40 percent increase in volume at age 4, its lack of statistical significance at this time identifies this treatment as unreliable compared to site prep and weed free, which led to more consistent reductions in cover.

Spruce mortality was related to cover (Fig. 1.10). The fresh clearcut (Firewood) developed extremely dense grass cover on one control plot, leading to lodging and burial under winter thatch. On the ineffective release plots, there may have been excess mortality due to hexazinone pellets landing near container seedling potting medium. Both site prep and weed-free treatments sustained little mortality.

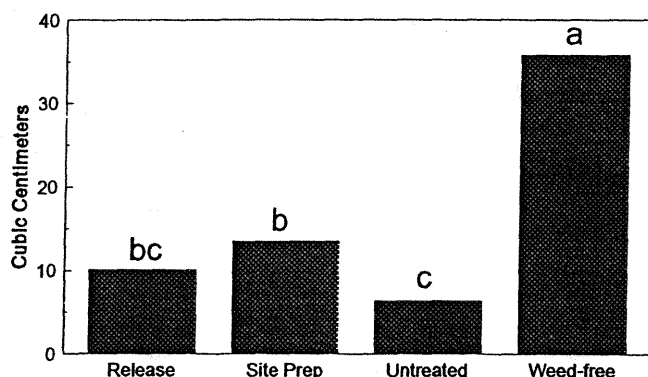


Figure 1.9. Stem volume/seedling in year four; data are pooled over sites for Fort Richardson Competition Study. Letters above columns which are the same are not significantly different at  $\alpha=0.05$  using Bonferroni's adjusted LSD.

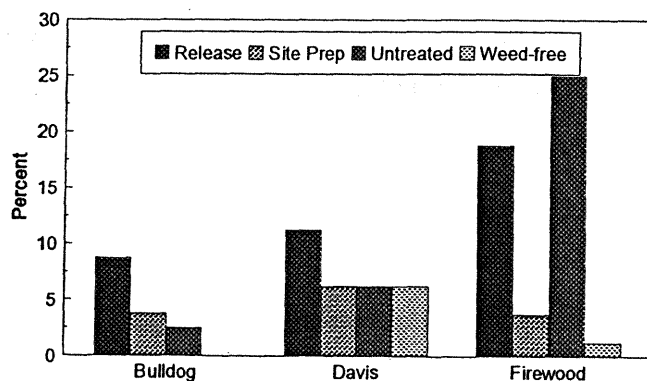


Figure 1.10. Percent mortality for spruce over four years for Fort Richardson Competition Study.

Birch sustained severe damage from freezing. Many seedlings died back to the ground repeatedly as the result of summer frost resulting from cold air drainage off the Chugach Mountains on clear summer nights during the period of active growth. After four years, many of the seedlings nearest the mountains were little taller than when planted, and some had live sprouts only an inch tall.

Growth estimates were compromised to a considerable extent by moose browsing. Many of the birch that were relatively free of competing cover were browsed. Despite loss of considerable height and foliage, there is still a pattern of considerably enhanced growth where competition is low (Figure 1.11), toward which diameter contributed substantially.

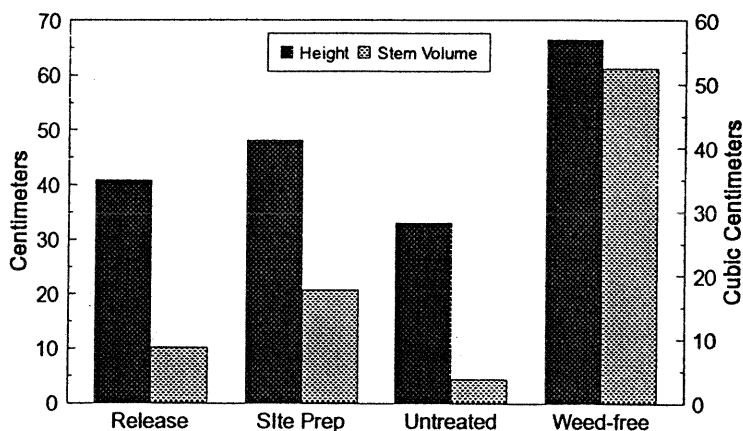


Figure 1.11. Mean height and stem volume/seedling after four years for birch seedlings Fort Richardson Competition Study.

Frequency of browsing on birch was highest on plots with least cover (weed-free) (Figure 1.12). Thus, there were counteracting forces influencing development: browsing on low-competition plots, and high resource availability on the same plots causing increased growth. The net effect of weeding was slightly positive on mean growth.

### *Mature forest conversion*

All seedlings in this study were planted the first season after logging and all growth data are for three years except the P-2 stock, which has been in the field two years.

The three spruce stock types behaved somewhat differently. The results were influenced to a decreasing degree by initial size in comparing the two plug types. The Eagle River plugs were somewhat larger than the Dean Creek (OR) plugs, yet the Dean Creek stock grew more in the first two years on both absolute and relative bases. After three years, the difference is small.

P-1 seedlings had by far the lowest relative growth rate of the spruces planted in 1993 (Table 1.1). However, P-1 seedlings had considerably greater absolute growth in the first two years than either plug, and in the third year relative growth rate more than doubled. Third-year absolute growth was much greater than that of plugs (Table 1.1). Figure 1.13 illustrates comparisons of the three spruce stock types overall, and shows the contribution of third-year growth to the total.

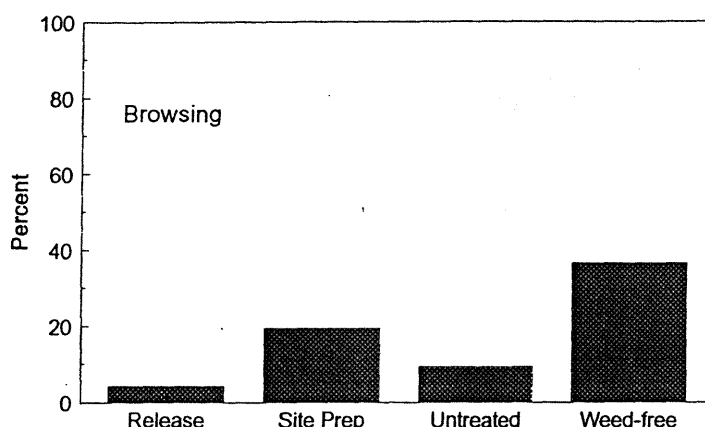


Figure 1.12. Percent browsing on birch seedlings by treatment averaged over all sites Fort Richardson Competition Study.

Table 1.1 Relative growth rates (based on stem volume/seedling) and third-year stem volume growth for three spruce stock types Fort Richardson Mature Forest Study.

Treatment	Relative Growth Rate Year 1			Relative Growth Rate Year 3			Stem Volume Growth Year 3 (cm <sup>3</sup> )		
	Plug-1's	Alaska Plugs	Oregon Plugs	Plug-1's	Alaska Plugs	Oregon Plugs	Plug 1's	Alaska Plugs	Oregon Plugs
Bladed	0.5	1.5	4.0	1.5	1.8	2.5	10.2	2.5	5.2
Site Prep	0.7	1.8	4.7	1.8	2.0	2.5	20.5	4.6	10.3
Spot Spray	0.6	1.4	4.1	1.8	2.1	2.1	13.5	4.1	5.7
Untreated	0.5	1.6	3.7	1.4	2.1	2.5	9.6	3.1	6.1

In this analysis note that it took P-1 seedlings until their third year to accelerate rapidly, whereas plugs had higher relative growth-rates in Years 1 and 2. P-2 seedlings that have been in the ground only two years are growing poorly. Many are yellow, and are attacked by adelgids in newly-emerged terminal shoots. However, they are not substantially worse-looking than P-1s at two years; hence, we are not ready to reject them as viable competitive stock. They remain taller, but with less stem volume, than P-1s planted a year earlier.

Treatments influenced all spruce stock types similarly. Site prep provided the lowest weed cover, and as expected, all stock types performed best there.

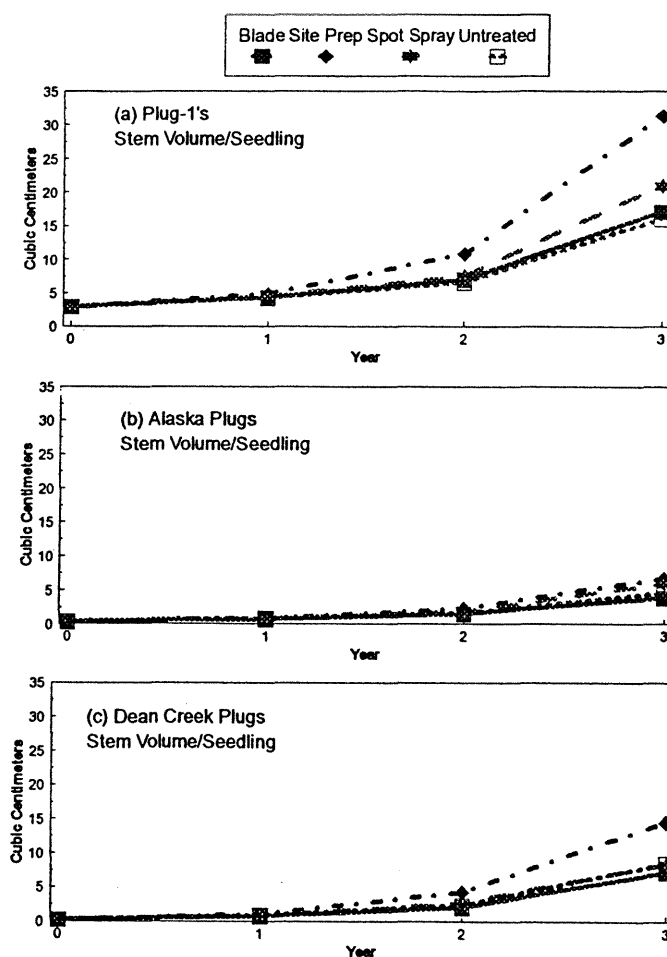


Figure 1.13 Stem volume/seedling for three spruce stock types Fort Richardson Mature Forest Plots.



Birch seedlings grew much better than those of the Competition study, presumably because of their nursery origin and also the site was not in a cold air pattern. No major differences were found among treatments for height, but the site preparation treatment had the greatest stem volume at age 3. Figure 1.14b illustrates a comparison of birch stem volumes by treatment. Again, height was badly compromised by browsing, but volume of stems shows a pattern much like that of the spruces.

Willow survival was not substantially affected by treatment. These rooted cuttings survived moderately well, independently of treatment. Size of crowns was greater in areas with low competition, but extreme variance obscured statistical differences among treatment, if any, in crown area or volume.

Browsing of willows tended to obscure differences in treatment effects, as well. Most willows were browsed in one or more years, suggesting that establishment had progressed at least enough to attract the moose.

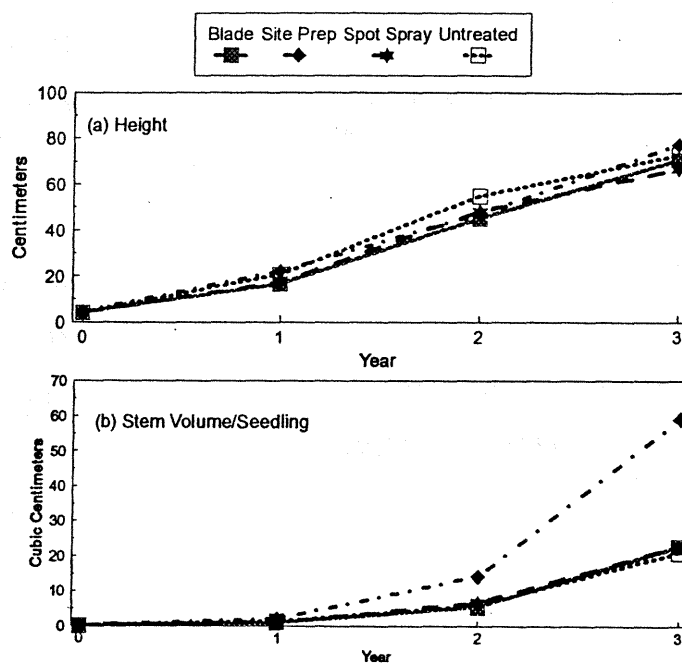


Figure 1.14 Birch annual height and stem volume/seedling by treatment Fort Richardson Mature Forest Study.

## SUMMARY

Overall, spruce at both locations demonstrated much-improved growth if planted soon after logging, regardless of weeding. Among the weeding treatments, those providing low weed cover in the first two years gave the best performance. Of these, the site prep sprays had relatively modest cost, and also provided reliable survival and excellent growth, apart from damage sustained in severe early freezing.

Birch responded to weeding much as did spruces. Good site prep and low competition in Year 1 provided a distinct improvement over all other treatments.

Among spruces, there are differences among types in performance. Transplant P-1 seedlings grew faster in total volume but less in percentage increase than either plug. Advantages of P-1s in height growth have only become apparent in the third year, but their total height and foliage mass is substantially greater than those of either plug type. They now appear to be considerably stronger competitors than plugs. This is a pattern widely seen with Douglas-fir, western hemlock, and other conifers in the Douglas-fir region (Newton et al. 1993; Stein 1995).

Rooted willow cuttings were relatively insensitive to site preparation and competitors. Attractiveness of willows to moose created considerable variability in growth, but it appears one can establish willows readily in a variety of conditions.

Overall, there are very large differences in spruce performance resulting from vegetation management and timely planting. Growth of plug spruce at Bonanza Creek in weed-free new clearcuts exceeds that of the same stock planted in 3-year-old clearcuts with grass/aspen cover by a factor of 39 plus in five years. In the new clearcut, a single site preparation treatment resulted in a 13-fold increase in growth. The almost six-fold difference in growth between the untreated plots of the new and old clearcuts illustrated the need for timely planting at Bonanza Creek. Much of the growth potential can be realized with a single, effective site preparation treatment on a recent clearcut, especially if burned. Total growth and maintenance costs are favored by coupling weeding and prompt reforestation with use of large seedlings.

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# REFORESTATION AND VEGETATION MANAGEMENT IN CENTRAL ALASKA

## II. CONTROLLING COMPETITION IN SOUTH CENTRAL ALASKA

Michael Newton and Elizabeth C. Cole<sup>1</sup>

### INTRODUCTION

The first section of this report outlines the way seedlings of white spruce and paper birch respond to a variety of competitive situations. It was observed in a general way that growth of both species is severely inhibited by competition, and that the prognosis for vigorous growth is directly related to the level and type of competition, and the interval between a disturbance such as logging and reforestation. The data reported indicate that there are major differences in efficacy of various vegetation control strategies.

Beginning in 1987, we undertook a series of experiments in Windy Bay, Alaska, on the southern tip of the Kenai Peninsula, and at the Bonanza Creek Experimental Forest, west of Fairbanks, to evaluate methods of controlling vegetation for purposes of establishing and releasing spruces, and also to favor browse conditions for moose and competitive conditions for establishment of paper birch. This report outlines the various experiments, and reports their results in terms of their objectives.

The research reported here includes numerous experiments involving herbicides as well as other methods of controlling herbs and shrubs. Each of these methods entails substantial interpretation regarding environmental effects. The environmental component of this work is summarized in part III of this series.

Experiments on which this report is based were initially designed on the basis of information already developed in Oregon and elsewhere in the Pacific Northwest. General concepts of forest vegetation management for growing conifers are outlined in Walstad and Kuch (1987) which also documents much of the progress in the Northwest.

We began the research by transplanting the approaches that were operationally accepted in the Douglas-fir Region as a beginning, and adapting and refining to

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<sup>1</sup> Professor and Senior Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR 97331

accommodate the needs of Sitka and interior white spruce. The novel needs for enhancement of browse for moose, and for establishing paper birch received attention after some initial work showed some basic response patterns of the species involved.

There are several components in competition control for growing both conifers and hardwoods. The first of these is the question of when in relation to planting time to do the weeding for maximum effectiveness and minimum impact. There is then the question of method of control and how to optimize whatever method is used. Finally, duration of efficacy has a major role in long-term plantation growth, as shown in the first paper in this series. This essay deals only with the relative efficacy of methods, and with ways of making each method most effective.

## METHODS

Several types of information were sought in these vegetation management experiments. Specifically, our informational objectives were focused on how to achieve a range of degrees of control for Alaska grasses, shrubs, and hardwoods while maintaining selectivity for the prevalent desirable conifers, hardwoods, and browse species, especially willows, as follows:

1. Establishment of an array of methods capable of controlling *Calamagrostis canadensis* without injuring conifers
2. Determine how to control Sitka alder, salmonberry, devilsclub, prickly rose, aspen suckers, and large paper birch trees without injuring conifers
3. Develop basis for broad-spectrum control of competition for site preparation for spruce, birch, and willow and for release of spruces.

Vegetation control methods for reforestation must optimize the window of opportunity for matching resource needs of conifers to the degree of resource release with weed control, both in quantity and in time. Duration of control as well as degree of initial freedom from competition are important criteria for efficacy. Operational feasibility is also crucial for economic use. Our evaluation will be given in terms of responses of vegetation

to specific treatments in the first one or two years. In discussion of these results, we will comment on feasibility, including a summary of how individuals may achieve the given results operationally on almost any scale.

The vegetation control experiments are of several types. Those involving shrubs entail applications to replicated plots of .01 acre (12 x 36 feet) or .025 acre (20 x 54.5 feet). Treatments included various combinations of active ingredient, dosage and timing of herbicides, and timing of manual controls. For herbaceous treatments, chemical applications consisted of various products applied at different rates to such plots during the spring dormant season for conifers. They also included hand scalping around individual conifers within such plots. Virtually all experiments included conifers, either previously planted or wildling seedlings naturally present in disturbed areas and suppressed by target vegetation. The exception to this pattern was an experiment to control overmature paper birch by injection. This was simply to evaluate the importance of choice of chemicals and season for injection of herbicides, and to determine if season of application influenced the various injectable products differently.

Two primary areas were selected for study--Bonanza Creek, near Fairbanks and Windy Bay, on the southern part of the Kenai Peninsula. Bonanza Creek is a low precipitation area located within the interior white spruce range. Annual precipitation is approximately 11 inches, with peaks in winter as snow and in summer as rain. Summers are warm and winters are cold, with few days above freezing. The area is high in site quality for white spruce, with dominant spruce 115 feet tall in 150 to 200 years.

Windy Bay is a high-rainfall area near the western limit of the range of Sitka spruce. It faces the Gulf of Alaska on the southern tip of the Kenai Peninsula. Summers are cool and wet; winters are milder than at Bonanza Creek with a mixture of snow and rain. A total of some 90 inches of precipitation are reported for the area. This area is one of moderately poor site quality for Sitka spruce, with dominant old-growth trees about 120-130 feet tall, and little evidence of rapid diameter growth despite the occurrence of stumps exceeding four feet in diameter. Both sites are representative of areas with major reforestation needs.

## RESULTS

### Coastal studies, Windy Bay

The experiments were installed in a series of 20-year-old, poorly stocked clearcuts resulting from harvest on lands originally in State of Alaska ownership, and now owned by the Port Graham Corp. Vegetation returning after clearcutting was dominated by Sitka alder on roadsides and other physically disturbed areas, and by grass, salmonberry, devilsclub and elderberry on areas of lesser disturbance; in the absence of shrubs there was grass. Soils are shallow ash deposits over glacial gravel on valley bottoms, and over breccia or graywacke bedrock on steeper slopes. The status of coniferous regeneration varied in the 20+ years since cutting. Along roadways and other disturbed areas were abundant suppressed spruce volunteer seedlings beneath the alder. These locations therefore provided the sites for a number of experimental plots. Behind the strips of alder along the road shoulder were mixtures of salmonberry, elderberry, and devilsclub. They were therefore valuable for multiple-species broad-spectrum control tests by chemicals and manual control studies. The openings behind the screens of alder often included areas of nearly pure grass. These provided the sites for our herb experiments.

### *Herb control--Experiment WB 1*

We evaluated herb control techniques in .02-acre (15 x 58 feet) plots in stands of *Calamagrostis* containing fireweed, horsetail, and scattered shrubs. *Calamagrostis* is a rhizomatous, sod-forming grass with extremely tenacious root systems. Fireweed has the capacity to occupy sites vacated by grass, hence both herbs are priorities for control. Great difficulty is experienced in planting in this cover because of the toughness of roots. Thus, we were interested not only in how to control competitiveness of the cover, but also to create more plantable conditions.

Six treatments were evaluated in this vegetation type, of which four were herbicide-based, one was manual scalping with a 3-foot square of sod removed, and one was an untreated control. All plots were planted with wildling spruce seedlings pulled from roadbanks nearby. All planting was done in early June, just before bursting of buds in the spruce. At this time, grass emergence had progressed about eight inches. Three of

the four herbicides were applied after planting; glyphosate had been applied the previous fall, in keeping with the normal use pattern for this product. Scalping was done immediately before each tree was planted. There was frost in the soil at depths of 6-12 inches, and this may have contributed to low vigor of planted trees because of broken roots when lifting the wild seedlings used in the test plots. Table 2.1 illustrates the cover ratings for these treatments, evaluated the following August.

Table 2.1. Percent cover evaluations for Windy Bay Herb Control Plots.

Treatment	Rate/Acre	% Cover			
		Grass	Forb	Other	Total
Untreated		36	42	8	86
Hand Scalp		16	40	8	64
Hexazinone	1.5 lbs	9	40	7	56
Imazapyr	0.5 lb	2	16	7	25
	0.75 lb	1	6	8	16
Sulfometuron	1.5 oz	9	22	8	40
	2.25 oz	3	27	3	33
Glyphosate	1.1 lb	0	5	15	20

Seedling growth was non-definitive, apart from showing that sulfometuron and imazapyr produced symptoms of injury. Scalping, hexazinone, and glyphosate treatments supported seedlings equal in vigor and growth to the control. The salient feature of differences in the treatments was that frost was gone from the glyphosate plots because of having been treated the previous fall, and soil was not as heavily thatched with an insulating layer of dead grass. The difference in difficulty in planting was dramatic, with fall-treated site preparation easy to plant, and all other treatments extremely difficult. The worst treatment for difficulty was hand scalping. The exertion required to remove a 3'x3' piece of sod was extreme. The rhizomes held this mat in one piece, and unless it was cut into small pieces, the whole square of saturated sod about 4-6 inches thick tended toward an estimated weight of 200 pounds. Thus considerable energy was spent cutting and hauling sod that was still attached to the ground. Efficacy of hand scalping toward reduction of cover was poor compared to herbicide treatments. Nevertheless, this



approach was comparable to these herbicides after two years in terms of vigor of seedlings.

Whereas subsequent experiments have demonstrated long-term growth patterns to require three or more years for evaluations, this experiment fails to provide useful data on long-term growth; all seedlings were still in planting check at the end of two years. Treatment differences occur only in terms of vegetation control and difficulty of execution. In this regard, it seems likely that glyphosate, applied in fall, will provide the most favorable result, and hand scalping the least, among the manipulative methods.

### ***Shrub control--Experiments WB 2 & 3***

Two series of experiments were installed at Windy Bay to evaluate efficacy of shrub control treatments. The two studies were installed in August 1988 and June 1989 for one, and August 1989 for the other. The first study (WB 2) evaluated season of application for manual control and 2,4-D, and used June applications for hexazinone, sulfometuron, triclopyr, and both granular and liquid imazapyr, but August application for glyphosate, as per Table 2.2. Most products were applied at more than one rate of application; sulfometuron and 2,4-D were applied at a single rate in combination. All herbicides were applied in two timed passes of five gallons per acre (total volume = ten gallons per acre) per pass with the waving wand technique, which will be described fully later. Manual treatments were applied with a chainsaw, with all woody stems other than spruce cut to within six inches of the ground in June or August, one time. Tables 2.2 and 2.3 display principal responses of several shrub species to these treatments. Crown reduction reflects the potential competition a year or more after treatment. Stem reduction shows the short-term effect on live height from which regrowth may or may not develop. Large numbers for crown reduction indicate a high likelihood of systemic kill.

Table 2.2 provides a summary of the degree of crown and stem reduction in Sitka alder achieved with each treatment. Manual release and glyphosate were the most effective in reducing crown volume of alder, followed by August application of a high rate of 2,4-D. Manual release was not followed by extensive sprouting, thus a single treatment

affected a substantial degree of control of this maturing alder. Occasional small alders did sprout.

Salmonberry did not respond to the same treatments in the same order (Table 2.3). Glyphosate, sulfometuron, or imazapyr all provided good or excellent suppression and kill of salmonberry. Manual, 2,4-D, and hexazinone treatments were essentially ineffective, with the manual treatment having more regrowth than untreated salmonberry. Triclopyr provided intermediate levels of control.

Table 2.2 Percent crown and stem reduction for Sitka alder, Windy Bay Shrub Plots (WB 2).

Treatment	Rate/Acre	Month	% Crown Reduction	% Stem Reduction
<b>2,4-D</b>	2 lbs	Aug	62 cde <sup>1</sup>	15 c
		June	39 fg	0 c
	4 lbs	Aug	77 bcd	15 c
		June	58 def	8 c
<b>Glyphosate</b>	1 lb	Aug	82 abc	37 b
	1.5 lbs	Aug	100 a	93 a
<b>Granular Hexazinone</b>	1.5 lbs	June	10 hi	8 c
	3.0 lbs	June	9 hi	0 c
<b>Granular Imazapyr</b>	0.75 lb	June	12 hi	0 c
	1.5 lbs	June	26 gh	10 c
<b>Liquid Imazapyr</b>	0.5 lb	June	54 ef	12 c
	0.75 lb	June	46 ef	6 c
<b>Manual</b>		Aug	94 ab	98 a
		June	94 ab	100 a
<b>Sulfometuron</b>	2.25 oz	June	16 hi	0 c
<b>Sulfometuron + 2,4-D</b>	2.25 oz + 2 lbs	June	40 fg	5 c
<b>Triclopyr ester</b>	1 lb	June	21 ghi	4 c
	1.5 lbs	June	18 hi	3 c
<b>Untreated</b>			3 i	1 c

<sup>1</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

Devilsclub responded significantly only to glyphosate and sulfometuron, and glyphosate provided the only useful degree of control. Glyphosate nearly eradicated devilsclub at the higher rate of application.

Experiment WB 3 for shrub control at Windy Bay was to evaluate fall applications of glyphosate + imazapyr mixtures. These have proven to be exceptionally effective, yet

safe for multiple-species control while maintaining selectivity (at lower rates) in Douglas-fir culture, and were deemed appropriate for testing over Sitka spruce. These treatments included rates of glyphosate acid equivalent from a half-pound per acre to 1.25 pounds, imazapyr from two to eight ounces acid equivalent, and mixtures containing glyphosate at .5 and .75 lbs plus two ounces of imazapyr per acre. Note that these imazapyr plots were in fall, as opposed to earlier plots that were applied in spring, with relatively marginal effect.

Table 2.3. Percent crown and stem reduction for salmonberry Windy Bay Shrub Plots (WB 2).

Treatment	Rate/Acre	Month	% Crown Reduction	% Stem Reduction
<b>2,4-D</b>	2 lbs	Aug	31 efg <sup>1</sup>	66 bcde
		June	40 def	96 a
	4 lbs	Aug	38 def	79 abc
		June	37 def	73 abcd
<b>Glyphosate</b>	1 lb	Aug	97 ab	93 ab
	1.5 lbs	Aug	98 a	90 abc
<b>Granular Hexazinone</b>	1.5 lbs	June	15 ghi	85 abc
	3.0 lbs	June	27 fgh	44 de
<b>Granular Imazapyr</b>	0.75 lb	June	80 ab	80 abc
	1.5 lbs	June	89 ab	84 abc
<b>Liquid Imazapyr</b>	0.5 lb	June	75 bc	90 abc
	0.75 lb	June	86 ab	93 ab
<b>Manual</b>		Aug	0 i	63 cde
		June	5 hi	78 abc
<b>Sulfometuron</b>	2.25 oz	June	94 ab	93 ab
<b>Sulfometuron + 2,4-D</b>	2.25 oz + 2 lbs	June	99 a	94 ab
<b>Triclopyr ester</b>	1 lb	June	53 de	95 ab
	1.5 lbs	June	56 bc	70 abcd
<b>Untreated</b>			24 fgh	39 e

<sup>1</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

Results of Experiment WB 3 demonstrated that glyphosate at 1.25 pounds, all rates of imazapyr and both mixtures provided over 90 percent crown reduction and 75 percent stem kill of all species, with salmonberry and devilsclub eradicated. Table 2.4 describes the differences between rates and combinations both for shrub control, and also for injury to spruce. It is notable that the glyphosate/imazapyr mixture with the lowest

rate of application succeeded in achieving excellent control of all brush species, and did not significantly injure spruce. The highest rate of glyphosate alone and in mixtures did cause measurable injury. Results of these experiments have been reported elsewhere (Newton and Cole 1991).

Table 2.4 Effects of combinations of glyphosate and imazapyr on Sitka spruce, Sitka alder, salmonberry, and devilsclub (WB 3).

Chemical & Rate (lbs ae/acre)		% Crown Reduction			
Glyphosate	Imazapyr	Spruce Rating <sup>1</sup>	Alder	Salmonberry	Devil's Club
0	0	.13 d <sup>2</sup>	2 d	0 d	0 c
.5	0	.23 d	82 c	96 a	83 a
.75	0	.27 d	83 bc	99 a	99 a
1.0	0	.39 d	85 bc	99 a	83 ab
1.25	0	.83 bcd	92 abc	97 a	100 a
0	.125	.57 cd	93 abc	65 c	0 c
0	.25	1.67 a	97 ab	80 b	100 a
0	.5	1.44 ab	100 a	99 a	23 bc
.5	.125	.31 d	94 abc	98 a	91 a
.75	.125	1.13 abc	92 abc	92 ab	50 ab

<sup>1</sup> Injury rating based on 6-point scale: 0=no visible injury, 1=slight injury to foliage, 2=injury to buds, 3=slight top dieback, 4=major top dieback, and 5=dead.

<sup>2</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

### Interior white spruce studies, Bonanza Creek Experimental Forest

#### *Herb experiments--weed control--Experiments BC 1 & 2*

Three sets of experiments were installed for evaluation of treatments to relieve herbaceous competition around white spruce regeneration. All were done in the Rosie Creek Burn area, which had previously been disc trenched and planted (1987) with Eagle River container white spruce. After the fire, this area revegetated quickly with a mixture of aspen, prickly rose, *Calamagrostis* grass, and other shrubs and herbs. The experiments were installed for initial screening for herbicide efficacy and conifer injury, then for refinement of the best treatments. The final experiment evaluated combinations of weeding and fertilization treatments to develop a scheme for overcoming the poor juvenile performance of white spruce.

Herb Experiment BC 1 entailed the application of weeding treatments on plots of .025 acre (20 x 54.5 feet) in the operationally planted area. Cover at the time of treatment was mostly *Calamagrostis*, with substantial components of fireweed and horsetail. Scattered *Phacelia*, prickly rose, bunch berry and elderberry were present. Planted spruce had been present for two years when the plots were laid out, in late May, 1989. There were about ten seedlings per plot at the time of treatment. Treatments included hand scalping of a 36-inch square around individual seedlings and 16 choices of herbicide treatment entailing nine different products or combinations of products, some of which were applied at different rates.

Liquid herbicides were applied mostly in May with broadcast applications done with the waving wand technique at 20 gallons per acre. Whereas normally one would use 5-10 gallons per acre, we were using a low-solubility hexazinone formulation, and hence used the volume that would carry the low-solubility product for all treatments. Three treatments entailed the use of granular herbicides (hexazinone as Velpar ULW, or imazapyr as Arsenal 5G). These were mixed with superphosphate fertilizer for ease of application with a small "Whirly Bird" spreader, with a total rate of phosphate of about 15 lbs/ac phosphorus, too little to influence efficacy. Glyphosate was applied in August. Spring applications were applied when grass was about 6 inches tall, and emerging from a heavy thatch of dead material about four weeks after snow melting. Little vegetation other than grass and prickly rose was in active growth.

Table 2.5 summarizes the cover that developed after the above treatments. It is notable that the untreated plots had nearly complete cover comprised of major components of grass, fireweed, and horsetail. Most of the treatments other than scalping and the low rate of liquid hexazinone modified composition of herbaceous cover to some extent, but variability severely reduced sensitivity of the tests. It was notable that glyphosate applied in fall, and a high rate of imazapyr applied in spring nearly eradicated grass, but most treatments other than hexazinone allowed horsetail to occur in much of the space grass had originally occupied. However, data from competition studies in the area indicate that the invasion of horsetail may not be a problem, since it does not appear to compete appreciably with established spruce. Atrazine, fluazifop, granular imazapyr,

granular hexazinone, glyphosate, and the highest rate of sulfometuron all suppressed fireweed significantly.

Spruce injury was severe in all imazapyr and sulfometuron plots after two years. There was slight but non-significant yellowing in some glyphosate plots. Hexazinone treatments were characterized by seedlings of excellent vigor, and minimum re-encroachment of horsetail. Hand scalping had excellent seedlings, but again was almost impossible to achieve with reasonable human effort.

Table 2.5 Percent covers for Bonanza Creek Grass Plots (BC 1).

Treatment	Rate ae/Acre	% Cover			
		Horsetail	Fireweed	Grass	Total
Atrazine	4 lbs	15 ab <sup>1</sup>	4 b	60 a	81 ab
Atrazine + 2,4-D	4 lbs + 2 lbs	13 ab	6 ab	37 ab	60 abcde
Fluazifop	0.4 lb	42 a	4 b	27 ab	78 abc
Glyphosate	0.75 lb	15 ab	0.2 b	32 ab	47 abcdef
	1.12 lbs	32 ab	0.4 b	0.1 b	33 cdef
Hand Scalp		22 ab	6 ab	7 b	41 bcdef
Granular hexazinone	2 lbs	3 b	3 b	4 b	12 f
Liquid hexazinone	1 lb	12 ab	10 ab	39 ab	64 abcde
	1.5 lbs	18 ab	8 ab	32 ab	61 abcde
	2 lbs	3 ab	7 ab	9 ab	21 ef
Granular imazapyr	0.75 lb	30 ab	4 b	35 ab	71 abcd
	1.5 lbs	38 a	2 b	7 ab	54 abcdef
Liquid imazapyr	0.5 lb	22 ab	7 ab	1 b	31 cdef
	0.75 lb	20 ab	5 ab	2 b	29 def
Sulfometuron	1.125 oz	30 ab	5 ab	18 ab	58 abcdef
	1.5 oz	18 ab	6 ab	12 b	39 bcdef
	2.25 oz	17 ab	2 b	22 ab	44 abcdef
Untreated		28 ab	15 a	42 ab	89 a

<sup>1</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

Experiment BC 2 had the objective of refining dosages and timings of the better treatments in BC 1. Specifically, mixtures of glyphosate and imazapyr, a slightly reduced rate of glyphosate, narrower dosage intervals of hexazinone and much-reduced applications of imazapyr were applied. In these trials, the granular hexazinone was mixed

with ammonium nitrate (34-0-0) fertilizer at the rate of 10 lbs N/ac for dilution. Table 2.6 summarizes the results.

Again, spruce showed severe injury from spring imazapyr applications, but no injury and excellent weed control from fall applications at very low rates. Glyphosate/imazapyr mixture provided the same result. Granular hexazinone provided nearly as good weed control, broad in spectrum, as did fall-applied imazapyr and combinations with glyphosate. None of these treatments other than granular hexazinone controlled horsetail significantly.

Table 2.6 Percent covers for grass, fireweed, horsetail, rose, forbs, and other shrubs from Bonanza Creek Herbaceous Plots (BC 2).

Treatment	Rate ae/Acre	Month	Spruce Injury <sup>1</sup>	% Cover					
				Grass	Fireweed	Horsetail	Rose	Forb	Other Shrub
Glyphosate + imazapyr	1.12 + 0.125 lbs	Aug	0.00 b <sup>2</sup>	3 c	1 c	45 a	0.5 b	1.0	4.7
Glyphosate	1.25 lbs	Aug	0.00 b	12 ab	3 ab	48 a	6.0 a	0.5	2.0
Granular hexazinone	1.5 lbs	June	0.09 b	5 ab	6 ab	6 b	1.5 b	1.0	1.2
Liquid hexazinone	1.0 lb	June	0.36 b	10 ab	15 a	40 a	1.3 b	1.0	1.0
	1.25 lbs		0.00 b	5 ab	9 ab	28 a	1.5 b	0.7	3.5
	1.5 lbs		0.47 b	4 ab	8 ab	25 a	2.0 ab	0.9	2.3
Imazapyr	0.125 lb	June	2.20 a	14 ab	3 ab	25 ab	2.5 ab	2.7	1.7
	0.25 lb		2.65 a	8 ab	2 ab	20 ab	1.2 b	1.3	3.5
	0.125 lb	Aug	0.22 b	3 c	1 c	48 a	0.8 b	0.5	4.7
	0.25 lb		0.48 b	0 c	4 ab	42 a	0.7 b	0.4	5.3
Untreated			0.00 b	28 a	5 ab	38 a	4.0 ab	1.0	3.0

<sup>1</sup> Injury rating based on 6-point scale: 0=no visible injury, 1=slight injury to foliage, 2=injury to buds, 3=slight top dieback, 4=major top dieback, and 5=dead.

<sup>2</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

### *Herb experiments, weed & feed--Experiment BC 3*

Experiment BC 3 inquired whether mixtures of hexazinone and nitrate fertilizer would either enhance activity of the herbicide, or give better growth of seedlings. These plots were an outgrowth of substantial research in Oregon that suggested that combining

hexazinone with nitrogen would substantially boost herbicide efficiency. Thus, we initiated a five-year experiment to evaluate both questions.

The experimental design evaluated nitrogen only, at 160 lbs/ac N as ammonium nitrate (34-0-0) alone and in combination with 1 or 2 pounds hexazinone per acre as the granular product (ULW), applied with superphosphate prills as a diluent. Fertilizer and herbicide were applied May 25, 1989 to plots of .025 acre, 20 x 54.5 feet. The granular materials were applied with a Whirly Bird applicator. The plots were installed on a three-year-old operational planting of white spruce.

Results after five years are illustrated in figures 2.1 and 2.2, reflecting effects on cover, and responses in tree growth over 5 years. These demonstrate that in order to achieve the most from herbaceous weeding and fertilization, they must be done together, and at a rate that provides maximum weed control. The occurrence of the greatest growth in plots with hexazinone only, and at the highest rate of application, demonstrates principally that seedlings grow best where competitive cover is light. At this point, it is notable that with the highest rate of hexazinone, it didn't matter whether there was fertilizer in the mixture.

It is also apparent that fertilizing without weed control increased the vigor of competition to the degree that spruce growth was suppressed. This was observed either with no hexazinone, or with a rate low enough so that weeds were simply thinned, after which they responded to form very vigorous stands. The seedlings with the least average growth and smallest average size (Fig. 2.1) were in the fertilizer alone and the low rate of hexazinone plus fertilizer treatments. Thus, here was our first solid evidence that long-term growth of white spruce was significantly controlled by herbaceous competition.

We also observed that application of nitrogen increased the relative competitiveness of fireweed. Applications of nitrogen alone caused a major increase in fireweed vigor, so that it substantially replaced *Calamagrostis* and horsetail on fertilized plots, even without herbicide. The fact that fireweed could out-compete grass and suppress spruce growth should remind a forester that there is a reason that nitrogen fertilization may be a poor idea on regeneration, especially with the realistic expectation of less-than-perfect weed control.



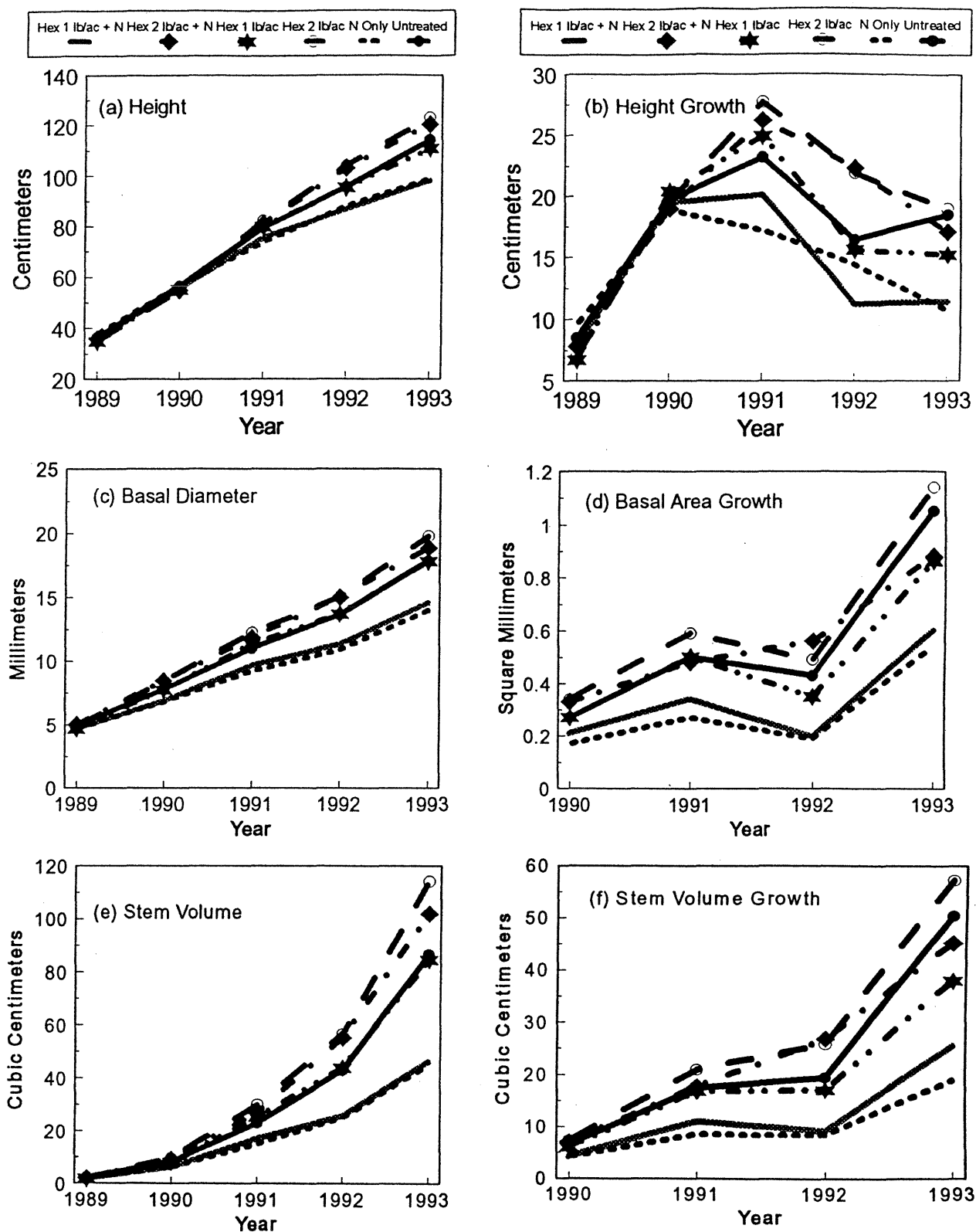


Figure 2.1 (a)Total height, (b)height growth, (c)basal diameter at 15 cm above ground, (d)basal area growth, (e)stem volume/seedling, and (f)stem volume growth/seedling by year for Bonanza Creek Fertilizer Plots (BC 3).

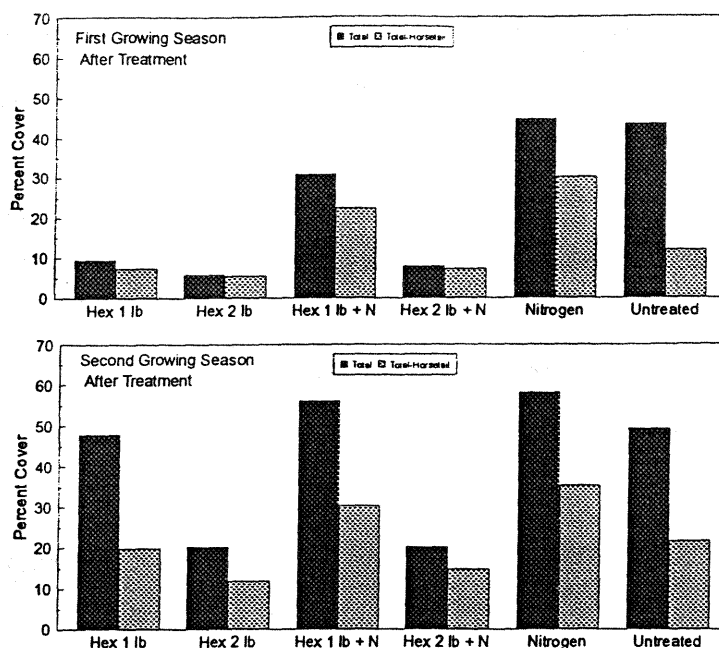


Figure 2.2. Percent total cover and percent total cover minus horsetail for the (a) first and (b) second growing seasons after treatment Bonanza Creek Fertilizer Plots (BC 3).

#### *Aspen control and release--Experiment BC 4*

The frequency of occurrence of aspen in cutover lands in interior Alaska demands that where spruce is to be regenerated, there is a need to prevent aspen from becoming dominant. Toward this end, we established a series of plots to evaluate manual and chemical treatments for release of plantations from aspen sucker stands in the Rosie Creek Burn. The spruce plantation was entering its third year, as previously noted. At the time of the experiment, the aspen suckers were about six years old and 2-8 feet tall. The understory was *Calamagrostis*-dominated, with fireweed, horsetail, and bunchberry present. The overstory was very dense aspen.

The experiment entailed nine herbicides or combinations of herbicides and rates of application, plus two seasons of manual application, to make up 20 treatment combinations. These were laid out in three replications, completely randomized, in rectangular plots of .025 acres (20 x 54.5 feet). Herbicides were applied with the waving wand technique in two passes of 5 gallons per acre total volume in each pass, for 10 gallons per acre, total, as water-based sprays. Applications were done for 2,4-D, sulfometuron, hexazinone, triclopyr, and imazapyr in late May; glyphosate, imazapyr, and

triclopyr were applied in August. Thus, imazapyr and triclopyr were applied both times. Manual control was done by chainsaw or knife in May and August in separate treatments, each cut once. All treatments were applied in 1989.

At the time of the May treatments, aspen foliage was partially expanded, and little terminal elongation had occurred. Thus, the foliage was probably inadequately developed to be an effective exporter of systemic herbicides.

Table 2.7 summarizes treatments and aspen crown development in the first two years after treatment of BC 4. Efficacy is inversely related to the crown cover, hence it

Table 2.7 Recovery of aspen and spruce injury two years after treatment (BC 4).

Treatment	Rate ae/Acre	Month	% Aspen Cover	Spruce Injury
<b>2,4-D</b>	2 lbs	May	30 abcd	1.12 bcde
<b>2,4-D +sulfometuron</b>	2 lbs + 1.5 oz	May	27 abcd	1.19 bcd
<b>Glyphosate</b>	0.75 lb	Aug	4 bcd	0.76 bcde
	1.12 lbs	Aug	7 bcd	0.75 bcde
<b>Manual</b>		May	38 ab	0.50 de
		Aug	33 abcd	0.93 bcde
<b>Hexazinone</b>	2 lbs	May	17 abcd	0.40 e
<b>Imazapyr</b>	0.4 lb	May	33 abcd	1.11 bcde
	0.6 lb		14 abcd	1.44 ab
	0.125 lb	Aug	47 a	--- ---
	0.25 lb		28 abcd	--- ---
	0.4 lb		32 abcd	1.39 abc
	0.6 lb		16 abcd	1.06 bcde
<b>Glyphosate + imazapyr</b>	0.75 + 0.125 lb	Aug	8 bcd	--- ---
	0.75 + 0.25 lb		2 cd	--- ---
	0.75 + 0.4 lb		0 d	--- ---
<b>Sulfometuron</b>	1.5 oz	May	35 abcd	1.93 a
<b>Triclopyr ester</b>	1 lb	May	32 abcd	0.94 bcde
	1 lb	Aug	22 abcd	0.69 cde
<b>Triclopyr ester + sulfometuron</b>	1 lb + 1.5 oz	May	22 abcd	1.46 ab
<b>Untreated</b>			37 abc	1.21 abcd

<sup>1</sup> Injury rating based on 6-point scale: 0=no visible injury, 1=slight injury to foliage, 2=injury to buds, 3=slight top dieback, 4=major top dieback, and 5=dead.

<sup>2</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

immediately becomes apparent that fall-applied mixtures of glyphosate/imazapyr are the most effective treatments, followed closely by glyphosate alone. As a practical matter, rates of imazapyr added to glyphosate at less than .25 lb/ac did not materially improve performance, and rates of .25 or higher are damaging to spruce regeneration. Thus, one might use the higher rate for site preparation, and use glyphosate alone for release. The low efficacy of imazapyr when used alone is remarkable in view of its high degree of efficacy on other species.

Hexazinone provided intermediate levels of control of aspen, but excellent control of understory herbage. Seedlings in this treatment were among the most vigorous. Moreover, this treatment is widely used in the Lake States and Ontario for control of aspen and herbs simultaneously. We have elsewhere applied triclopyr or glyphosate to aspen in late summer (Newton et al., 1992) with the observation that these products are nearly equal in efficacy when applied to mature foliage. Manual control, which provided total removal at the time of cutting, led to rapid recovery and proliferation of new suckers. These suckers were much shorter than the original suckers, hence were not as effective in shading the spruce. However, they are growing much more rapidly than the spruce, and will soon overtop all released seedlings. Nevertheless, the seedlings so released are at least temporarily in excellent condition.

There were significant differences among treatments with respect to spruce condition. Those released with hexazinone were in the best vigor, closely followed by manual and glyphosate treatments. Treatments entailing sulfometuron were consistently damaging, as were those with high rates of imazapyr. No seedlings were present in the plots treated with glyphosate and the low rate of imazapyr, but plots from Windy Bay with Sitka spruce suggest that the low rate is safe on at least one species of spruce, much as with Douglas-fir. Conifer injury ratings are shown in Table 2.7. Unfortunately, the absence of spruce in the glyphosate/imazapyr plots precluded evaluation of their release in the most effective treatments. However, Figure 2.3 illustrates the general gain in crown position with various degrees of crown reduction of aspen. We have had the opportunity to revisit these plots, and conclude that the glyphosate/imazapyr low dosage plots would provide excellent environments for spruce in aspen sucker thickets.

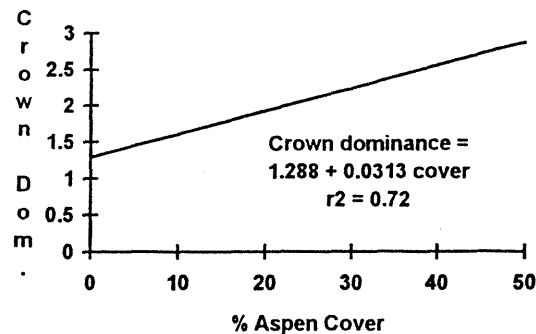


Figure 2.3. Correlation of spruce crown position with aspen cover. Spruce crown position 1=Dominant, 2=Codominant, 3=Intermediate (BC 4).

### *Interior alluvial spruce sites--Experiment BC 5*

Some of the best interior spruce sites along the Tanana and Yukon River flood plains have serious problems with invasions by prickly rose, willow, elderberry, green alder and other shrubs, plus *Calamagrostis* and fireweed, to the detriment of spruce regeneration on clearcuts. We installed a series of experiments on Willow Island, about 10 miles west of Fairbanks in the Tanana River, to evaluate treatments for selective control of this complex. The site on Willow Island was in a four-year-old clearcut, adjacent to a series of plots used by Youngblood and Zasada (1991) of the US Forest Service, Institute of Northern Forestry to evaluate site preparation for artificial regeneration. There was a nucleus of regeneration in these plots, some of which was excessive in quantity, but suppressed by shrubs and grass.

We established a completely randomized experiment with three replications, to evaluate 11 treatments. Plots were .025 acre, 20 x 54.5 feet. Treatments included 2,4-D, triclopyr, sulfometuron, hexazinone, imazapyr, and glyphosate. All treatments were applied in late May except glyphosate, which was applied in late August, 1989.

Table 2.8 lists treatments, mean crown reduction for prickly rose and injury to white spruce, if any. Rose was damaged most by imazapyr at .25 lb/ac or hexazinone at 2.0 pounds per acre, both quite high dosage rates for interior Alaska, in terms of cost. Sulfometuron at 1.5 ounces per acre, plus 2 pounds 2,4-D, resulted in reasonably good control, as did 1.0 or more pounds of triclopyr per acre. The triclopyr did the best job of

killing stems, but many of these later sprouted, albeit with less vigor than was observed in controls. None of these treatments injured spruce significantly except those entailing sulfometuron. In view of the low rate of sulfometuron used, this was a signal that spruce is highly vulnerable to injury from this product at rates that produce marginal grass and rose control.

Table 2.8 Crown and stem reduction for prickly rose in 1989 and 1990 and spruce injury 1990 (BC 5).

Treatment	Rate ae/Acre	1989		1990 <sup>1</sup>		1990
		% Crown Reduction	% Stem Reduction	% Crown Reduction	% Stem Reduction	Spruce Injury <sup>2</sup>
2,4-D	2 lbs	46 d <sup>3</sup>	26 de	49 b	21 ef	0.21 c
Sulfometuron	1.5 oz	48 d	30 cd	49 b	32 def	1.00 ab
Sulfometuron + 2,4-D	1.5 oz + 2 lbs	69 bc	53 b	49 b	29 def	1.21 a
Glyphosate	0.75 lb			91 a	45 bcd	0.44 bc
	1.12 lbs			88 a	36 cde	0.15 c
Hexazinone	1.5 lbs	60 cd	23 de	50 b	36 cde	0.44 bc
	2.0 lbs	80 ab	32 cd	78 a	65 ab	0.12 c
Imazapyr	0.25 lb	90 a	44 bc	78 a	78 a	0.58 bc
Triclopyr ester	1.0 lb	71 bc	96 a	54 b	58 abc	0.31 c
	1.5 lbs	72 bc	88 a	45 b	63 ab	0.10 c
Untreated		17 e	8 e	26 c	10 f	0.52 bc

<sup>1</sup> 1990 are for two growing seasons after treatment except for glyphosate, which is one growing season after treatment.

<sup>2</sup> Injury rating based on 6-point scale: 0=no visible injury, 1=slight injury to foliage, 2=injury to buds, 3=slight top dieback, 4=major top dieback, and 5=dead.

<sup>3</sup> Means within columns followed by the same letter are not significantly different at  $\alpha=0.05$  using Tukey's.

Table 2.9 summarizes residual cover on plots after the May treatments, by species group. Imazapyr at .25 lb/ac resulted in the lowest cover rating, but the response of herbs to the rest of the treatments was too variable in composition to lead to important differences in total cover, despite strong visual differences in degree of control over individual species.

Table 2.9 First-year cover evaluations for Willow Island Rose Plots (BC 5).

Treatment	Rate ai/Acre	% Cover					
		Grass	Forb	Fireweed	Horsetail	Rose	Total
2,4-D	2 lbs	3.0 a <sup>1</sup>	5.3 a	3.3 a	2.3 ab	7.7 a	34 ab
Sulfometuron	1.5 oz	1.3 a	1.3 a	2.3 a	2.0 ab	11.7 a	24 ab
Sulfometuron + 2,4-D	1.5 oz + 2 lbs	4.0 a	1.0 a	1.7 a	1.7 b	9.0 a	22 ab
Hexazinone	1.5 lbs	8.3 a	2.0 a	5.7 a	3.3 ab	7.7 a	34 ab
	2.0 lbs	0.7 a	9.3 a	2.0 a	1.0 b	3.7 a	23 ab
Imazapyr	0.25 lb	0.7 a	2.3 a	0.7 a	3.7 ab	1.0 a	14 b
Triclopyr ester	1.0 lb	16.0 a	1.3 a	3.3 a	3.0 ab	5.3 a	35 ab
	1.5 lbs	3.0 a	1.3 a	5.0 a	2.0 ab	5.0 a	23 ab
Untreated		8.7 a	7.0 a	3.0 a	5.0 a	8.0 a	40 a

<sup>1</sup> Means within columns followed by the same letter are not significantly different at alpha=0.05 using Tukey's.

### *Interior browse enhancement study--Experiment BC 6*

Carrying capacity for moose in Alaska is low, despite the fame of this wildlife species and importance of hunting in Alaska. While managing early successional vegetation for promotion of tree growth, there is a window of opportunity for simultaneously enhancing forage development for moose, most particularly willow sprouts. We evaluated a number of treatments that might either release willows from other vegetation, or alternatively maintain willows while treating for multiple objectives.

The rationale for these treatments was that sprouts provide nutritious browse material with a high ratio of current-year bark, buds and pith available as high-quality forage for moose. Primary browse species are vigorous sprouters, hence we hypothesized that treatments capable of top-killing the shrubs without damaging roots severely would rejuvenate the shrubs and bring them within reach of ungulates. We therefore selected a series of herbicide treatments which at one or another time of year would likely top-kill shrubs. We also included several treatments that would likely be used for spruce release to determine whether they would inhibit or stimulate willow development.

We selected a roadside treatment area in the Bonanza Creek Experimental Forest where heavy stands of mixed green alder, aspen, willow, elderberry, and spruce

regeneration provided an opportunity to evaluate selectivity among treatments. Among the potential top-killing products were glufosinate (Ignite®, a desiccant), 2,4-D in spring, triclopyr in spring, and glyphosate in spring. Among the systemics more widely used for spruce culture were hexazinone in spring, triclopyr in fall, and mixtures of glyphosate with or without imazapyr, in fall.

In brief, 2,4-D, or a mixture of glyphosate and 2,4-D, in spring, was the closest to providing selective control of other shrubs while enhancing willows of three types. However, none of the treatments provided for the vigor one expects from cutting willows. The fall applications that might generally be valuable for spruce release severely curtailed willow sprouting. Table 2.10 describes three phenotypes of willow, not specifically identified as to species, in their responses to the array of treatments used. None of the willows had resprouts taller than three feet. Information relating to the responses of the other shrubs is available from either author on request, but is consistent with other data presented in this report where the individual species are present.

### **Browse enhancement experiments, Ft. Richardson**

After failing to demonstrate clear preferences for any of the vegetation management treatments used in general silviculture for enhancing moose browse, we installed a series of plots in second-growth forests where moose range is a primary objective of the Ft. Richardson resource management plan. These experiments entailed a series of vegetation control treatments, followed by planting two willow types that had been propagated in nursery beds from cuttings. The treatments utilized both mechanical and chemical components, recognizing that mechanical removal of cover would stimulate sprouting of existing willows, and that weeding might be essential for establishment of planted willow ramets as rooted cuttings.

The sites used for this experiment included three areas that had been cleared for military training exercises 7 to 15 years previously. Cover included an abundance of eight phenologically different willow types, paper birch, Sitka alder, aspen, balsam poplar, white spruce regeneration, Labrador tea, fireweed, horsetail, and grass. The six treatments were



Table 2.10 Resprouting for willows on Bonanza Creek Browse Plots (BC 6).

Treatment	Rate ae/Acre	Month	Large	Hybrid	Shiny
			------(ft)-----		
2,4-D	1.0 lb	June	1.9 abc <sup>1</sup>	-- --	1.5
	2.0 lb		2.3 ab	2.3 a	1.3
Glyphosate +imazapyr	0.5 +0.125 lb	June	0.4 bc	0.2 ab	0.6
		Aug	0.8 abc	0 b	0.1
Glyphosate +2,4-D	0.5 +2.0 lbs	June	2.7 a	-- --	2.0
		Aug	1.3 abc	0.8 ab	0.5
Glyphosate	1.0 lb	June	1.0 abc	0.1 b	0
		Aug	0.2 c	0.2 ab	1.2
Granular hexazinone	1.5 lbs	June	0.8 abc	0.2 ab	0
Liquid hexazinone	1.5 lbs	June	0.2 c	0.5 ab	0.5
Ignite	1.0 lb	June	0.4 bc	0 b	0
		Aug	0.7 abc	0 b	0
Triclopyr ester	1.0 lb	June	1.5 abc	0.5 ab	0
		Aug	1.1 abc	1.7 ab	0.4
Untreated			0.0 c	0 b	0

<sup>1</sup> Means within columns followed by the same letter are not significantly different at  $\alpha=0.05$  using Tukey's.

installed on half-acre plots, and included four with mechanical clearing, of which one combined mechanical with chemical, one with chemical only to control conifers and herbs, and an untreated control. Three replications were of somewhat different ages, but were of generally the same species composition. The two willows were planted after treatment, with 18 to 27 rooted cuttings on each plot, depending upon available rooted material.

Specifics of the treatment were as follows:

1. Control. No removal of any cover; planted under existing canopy
2. Hydro-Ax clearing flush with ground
3. Hydro-Ax clearing, followed by application of 600 pounds per acre of 16-16-16 fertilizer

4. Hydro-Ax clearing, followed by spring application of 0.75 lbs/acre hexazinone for herb control
5. Mechanical crushing with D-7 tractor with blade held at ground surface, roots intact
6. Fall application of glyphosate, hexazinone, and metsulfuron to control both conifers and competing shrub cover

The mechanical clearing was done in early spring prior to planting in late spring. Fertilizer was applied in late spring after planting.

Figure 2.4 illustrates the changes occurring in total cover, by height class, during the two years after treatment. Of paramount importance to forage is the cover less than a meter tall, and also cover 1-2.5 m tall during winter. The left bar in each of these diagrams represents the condition at the time of treatment, the center bar represents first-year recovery or change from the initial untreated condition, and the right bar shows status after two years. Each of these shows that the mechanical treatments essentially removed tall cover completely, and that negligible cover in those treatments exceeded 2.5 m after two years. Cover less than one meter was greater than previously only one year after the mechanically treated areas were cleared, and those Hydro-Ax treatments had approximately doubled initial low cover value by year 2. On untreated plots, the tall cover was so dominant that low cover was substantially suppressed. The mixed chemical treatment changed species composition in favor of conifers, despite the metsulfuron, hence did not achieve the objective.

Figure 2.5 demonstrates the degree to which willows were represented in the re-developing cover. Again, all treated plots except herbicide alone showed a major improvement in available willow cover below 2.5 meters tall; herbicides alone reduced cover below initial conditions, after which willows did recover to their initial cover value at less than a meter. Proportion of willow as well as total willow cover appeared to respond favorably to fertilizer.

Figure 2.6 illustrates the frequency of cover utilization by moose during the summer, hence probable relative value of forage grown. The upper frame shows absolute

utilization based on intensity of browsing on aspen, willow, and birch as measured by ocular estimation of approximate loss of individual shrub crowns. The lower frame illustrates the above utilization adjusted for absolute cover, for determination of an index of total forage used by moose.

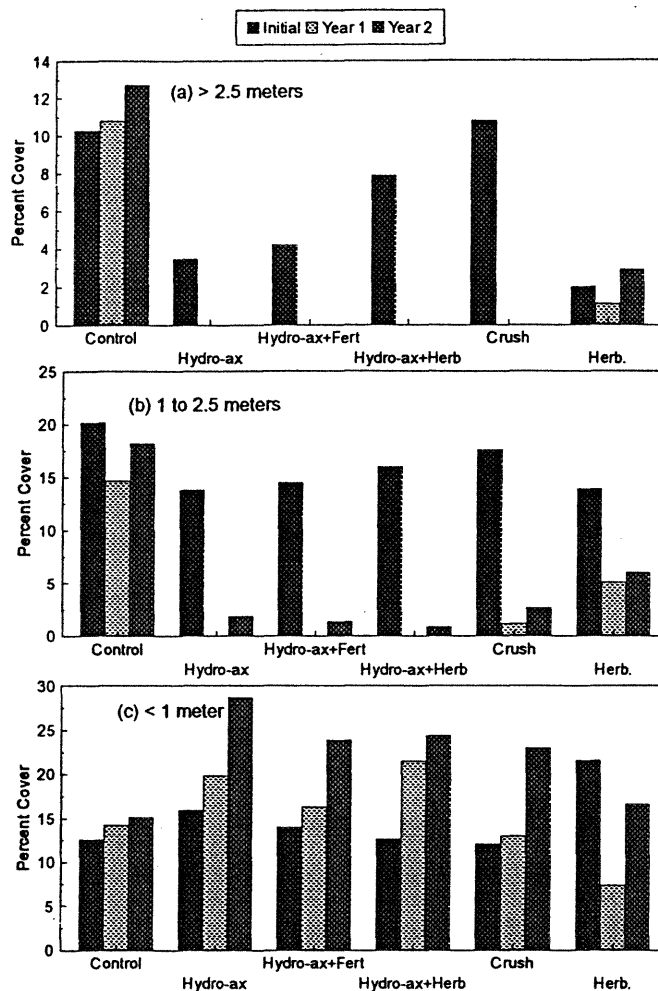


Figure 2.4 Total shrub cover by layer (a) > 2.5 meters, (b) 1 to 2.5 meters, (c) < 1 meter for Fort Richardson Browse Enhancement Sites.

Combining Hydro-Ax operation with fertilizer was clearly distinct from all other treatments in terms of browse utilization. Crushing had some of the same effect, but Hydro-Ax alone was less utilized than any treatment other than the control. Thus, the partial contribution of fertilizer must be regarded as crucial to the value of the mechanical program.

The planted willows were very similar in appearance, and the two “types” may actually be the same species. In any case, they were established satisfactorily any place there was relatively little overhead cover or competition. Plantings failed or were failing under untreated cover, or where sprayed cover remained dominated by spruces (Figure 2.7). Crown development, measured in terms of crown volume, did not significantly vary by treatment, because of the high variability of willows within a treatment. However, for both willow types, all treatments had mean crown volumes greater than the untreated (Table 2.11).

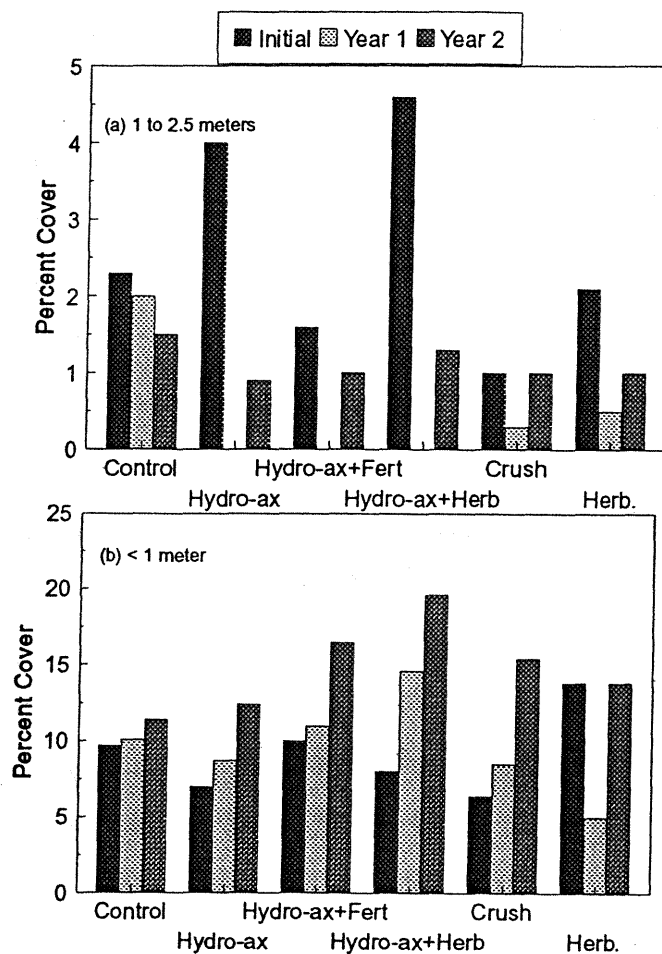


Figure 2.5 Willow cover by layer (a) 1 to 2.5 meters and (b) < 1 meter for Fort Richardson Browse Enhancement Sites.

Where there is no willow, planting will establish desirable browse plants. Whether cuttings need to be rooted before planting is doubtful, and whether they need herbaceous weed control is also doubtful if there is substantial clearing of the site at the time of

planting. Moose did utilize the larger plantings, but many of the smaller slips remain too small to attract attention after two years, and we expect some additional mortality of suppressed willows.

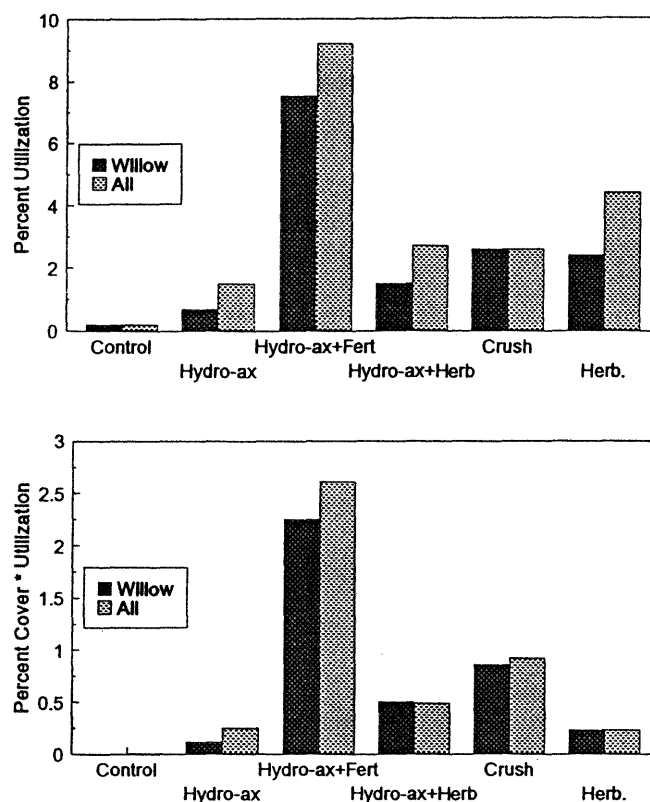


Figure 2.6 Summer utilization of willow and other species (willow, aspen, balsam poplar, and birch included) by moose Fort Richardson Browse Enhancement Sites.

The net combined effect of utilization by moose and treatment focuses our attention on fertilization. Whereas we noted that fertilization was associated with improved relative abundance and also total willow cover, this was observed where browsing was twice to ten times the levels of utilization on other treatments. Thus, we postulate that fertilization had a greater effect on cover than shown by net cover changes.

These plots were subjected to substantial moose browsing pressure during the winter. Browsing did not influence spruce seedlings in any substantial way. Browsing was a problem for the Ft. Richardson management scheme only in that the continuous pressure on willows, birch, and aspen permitted spruce to become dominant, to the eventual detriment of browse material. We expect that a multiple cropping system in which mixtures of willow and birch are enhanced could be compatible with spruce,

provided spruce is planted at a wide enough spacing to prevent early suppression of browse, and early weed control protects the spruce.

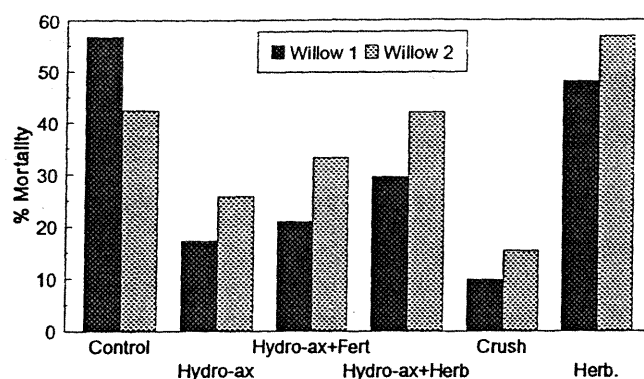


Figure 2.7. Mortality after 3 years among treatments for two willow types Fort Richardson Browse Enhancement Sites.

Table 2.11 Crown volume of planted willows in year 3 and relative increases over the Untreated and Hydro-Ax treatments for Fort Richardson Browse Enhancement Sites.

	Willow 1			Willow 2		
	Crown Volume (cm <sup>3</sup> )	% Increase over Untreated	% Increase over Hydro-Ax	Crown Volume (cm <sup>3</sup> )	% Increase over Untreated	% Increase over Hydro-Ax
Crush	24694	1200	170	24405	780	110
Herbicide	11139	490	20	3976	40	-30
Hydro-Ax	9307	390	--	11789	330	--
Hydro-Ax + Fertilizer	57170	2910	510	16609	510	40
Hydro-Ax +Herbicide	21339	1020	120	15768	470	30
Untreated	1900	--	-80	2769	--	-80

### Interior paper birch injection experiment--Experiment BC 7

There are numerous operations in which large residual birches represent unmerchantable competitors to spruce, or in which one may wish to create wildlife snags from cull birch in mature stands. We installed an experiment to determine whether

chemical injection methodology developed in northeastern US would adapt to Alaska paper birch.

We used a mature stand of spruce that contained patches of overmature (>100 years old) paper birch with substantial evidence of decay for this experiment. Among treatments, we evaluated four water-soluble herbicide products at two times (late May and late August) of application, and two or more dilution rates. Each product and dilution combination was applied at each season to three groups of five mature trees each. Tree diameters ranged from 7 to 21 inches.

All products and dilutions were injected in axe-cuts spaced equally so that there was one cut per two inches diameter, or 6.3 inches between centers. Into each cut was placed 1 ml of the appropriate product or dilution. Diameter was recorded for each tree treated.

Second-year results are displayed in Table 2.12. Imazapyr was clearly the most effective product. In August, dilution rate made little difference, since virtually all levels of dilution down to eighth-strength killed virtually all treated trees outright. Spring applications showed considerably less effect and a strong relation between concentration and crown reduction. Efficacy of spring treatments was reduced by a strong positive pressure sap flow at the time of application, which probably flushed some of the chemical out of the cuts. Glyphosate showed substantial activity with August treatments, and many of those trees were weakening further when last evaluated. However, spring glyphosate treatments were ineffective, as were those at either season with 2,4-D or triclopyr. Making injection cuts without introducing chemical did not produce any response, regardless of season.

These treatments demonstrated what has been shown in the Pacific Northwest by Cole et al. (1989) where large hardwoods resistant to most injectable herbicides were susceptible to imazapyr at low concentrations, but that summer applications were more effective than those applied when leaves were in the early expansion stage or earlier. The first author (unpublished information) has also observed that the behavior of Alaska birch appears intermediate between responses of paper and yellow birches in New England. He has also observed that even with red alder, which is susceptible to 2,4-D and triclopyr

amines, susceptibility is poor from mid-winter to after leaf expansion. Yet with alder, oak and Pacific madrone, imazapyr is effective year-round. Thus, we conclude that Alaska paper birch is in the difficult-to-control category, but is highly susceptible to low doses of imazapyr in mid to late summer. Further experimentation would be needed to determine the minimum doses needed to control or space smaller trees, since required dose per diameter inch tends to increase sharply with size of tree.

Table 2.12 Percent crown reduction for birch (BC 7).

Treatment	Product % Concentration	Month	% Crown Reduction
2,4-D amine	50	May	2 h
	100		5 gh
	50	Aug	10 fgh
	100		10 fgh
Glyphosate	25	May	3 h
	50		10 fgh
	25	Aug	61 bc
	50		54 bcd
Imazapyr	12.5	May	45 cde
	25		31 def
	50		71 b
	12.5	Aug	98 a
	25		99 a
	50		100 a
Triclopyr amine	25	May	9 fgh
	50		0 h
	25	Aug	13 fgh
	50		28 efg
Hack Only		May	4 h
		Aug	4 h
Untreated			6 gh

<sup>1</sup> Means within columns followed by the same letter are not significantly different at  $\alpha=0.05$  using Tukey's.

## GROUND APPLICATION METHODS

Most of the chemicals used for vegetation control in Alaska's forests can be applied in liquid form, either emulsions, suspensions, or solutions, in water. Chemicals



must be distributed uniformly within the target area to avoid excessive (injurious, costly) dosages or skips.

We used two general methods of spraying in our Alaska studies that give results quite similar to aerial treatment at comparable or lower cost. The most generally useful method is the "waving wand" method of broadcast application (Newton and Knight 1981). Spot treatment, applied with a single nozzle or short boom, also has some utility. Use of granular products has some merits if applied at the proper timing for soil-active materials.

The waving wand treatment entails use of backpack sprayers with single nozzles or power guns on 4-wheelers. With this method, the operator travels a straight line at a uniform speed, swinging the nozzle back and forth to 70-80° both sides of the line of travel, with the nozzle elevated 15-45°. Never point the nozzle directly toward the crop tree, for fear of injuring it. The nozzle should be an adjustable solid cone system similar to the Chapin® or Cooper-Pegler® nozzles. These nozzles deliver 0.8-1.1 qt/minute at 20-30 psi when adjusted to give a coarse spray that will project 20-23 feet. When traveling at 1 mile per hour, the swinging nozzle should be providing a swath 30-35 feet wide. A Gun-Jet® will deliver more volume over a wider swath.

To calibrate delivery rate per acre, an applicator must determine the area the spray has covered and the time required to cover that area. For example, if a swath 32 feet wide is run for 0.25 mile, the spray has covered exactly one acre. The desired application rate is 5 gallons per acre. If a 5-gallon sprayer is equipped with a nozzle that delivers all its liquid in 15 minutes, then the applicator would need to walk the quarter-mile long swath at one mile per hour. If the distance actually covered in the calibration trial is shorter than the 0.25 mile, then the applicator would need to increase the walking speed; if the distance covered were longer than 0.25 mile, then the applicator would need to travel more slowly. When the applicator can make consistent deliveries of a certain number of gallons of water per acre, the requisite amount of chemical can be added to the water to make up the right dosage of active material per acre. So, with this method, it is the delivery rate per acre in a broadcast spray that is crucial, rather than the concentration shown on labels for spot spraying.

The chemicals are purchased in various concentrates. Glyphosate is usually 3 pounds acid equivalent per gallon. Triclopyr and 2,4-D are likely to be 4 pounds per gallon; liquid hexazinone contains 2 pounds per gallon. If one is applying 5 gallons of liquid spray per acre and wishes to put 1.1 lb ae/acre glyphosate, then one needs  $1.1 \div 3 = .366$  gallon (1.5 quarts) of product per acre. If mixing in a sprayer, the operator should fill the sprayer 2/3 full with water, add chemical, shake vigorously to mix, then fill to five gallons with water and shake vigorously again. If batching in a tank to cover 10 acres, mix 3.66 gallons product to make up 50 gallons total spray, agitating during mixing.

Keeping track of the spray pattern takes practice. Use of a string to mark the swath will give the operator a visible guide. Very fine string, such as brightly-colored hip-chain thread, will work. A visible trail in grass also works.

Optimum crew organization may require several backpack operators plus a 4-wheeler with tank or bladder or tank on a pick-up to handle several hundred gallons. Keeping track of patterns is facilitated if several workers line up so that one guides on a previous swath marker; the other sprayers guide on the leader and each other to keep proper intervals and speed.

The spot sprayer uses the same principle of applying a known amount of spray in a known but small area. A 5 x 5-foot square is only 0.00057 acre, but 1000 spots this size are 0.57 acre. If one applies chemical with a flat fan nozzle simply by holding the nozzle far enough off of the ground to make a swath 5-feet, and, while walking, turns the nozzle on in passing so that it is spraying for just 5 feet, a 5 x 5-foot spot is treated. If the sprayer walks at a comfortable speed and finds that a load treats 1000 spots, the chemical used per filling should be 0.57 x the dose for one acre.

We do not recommend use of a solid cone nozzle for spot spraying. Dose varies across the pattern. To stand and describe a circle around each seedling provides uncontrolled dosage per square foot and is very time consuming. Instead, a steady speed along rows of trees, 2 mph or less, will cover a lot of ground economically. For best results, a commercial flat fan nozzle, such as a Spraying Systems 9502E® is suggested.

Under some circumstances, granular products, such as the 75% active hexazinone, may be used to good effect. These are soil-active products that must be applied at a

timing that brings several inches of precipitation between application and development of target weeds. Fall may be the best timing in central Alaska; spring may be preferred on the coast.

Highly concentrated granules cannot be spread effectively and uniformly in equipment designed for fertilizer unless the product is diluted with fertilizer-size granules which are similar in size to the herbicide granules. Low-volume spreading is possible with specialized aircraft-mounted spreaders. Hexazinone granules of intermediate concentrations (5 or 10% active) are routinely spread by helicopter in the Southeast USA.

Granules have the advantage that they are perceived as having no drift or smell, and they may be regarded by some as no more "dangerous" than fertilizer. The actual hazards are related to dusts, however. Hexazinone dust is irritating to nasal passages and eyes, and exposure should be avoided in terms of personal comfort. Glasses and respirator should be worn by bulk handlers, and workers should not be put in poorly ventilated areas where dust inhalation cannot be avoided.

All pesticides, of which herbicides are a category with low risk to humans, are regulated by state and federal laws. The label is a legally binding document, and it is unlawful to use a product in any way prohibited on the label, including excessive dosages or on crops not specified. All the herbicides listed in this report other than glufosinate and fluazifop are federally registered for use in forests to enhance conifers. State registration may vary from federal registration. When using the waving wand low-volume applications, it is normally acceptable to use mixtures prescribed for aerial application, but users are advised to seek the counsel of local authority when extending interpretations of labels.

Worker Protection Standards are also required for pesticide applications. The standards include training and safety requirements for applicators and others who would be working in or near treated areas. The products listed here are in categories for which certain clothing and protective gear are required; for example, gloves must be worn when handling concentrates. Specific requirements are found on labels. Consult and have copies of local Worker Protection regulations, which may vary from federal standards.

Also, it is essential to keep copies of Material Safety Data Sheets in the workplace available to all who handle these regulated products.

A number of substances forest workers use are more hazardous in personal exposure than are herbicides, but are not regulated in the same way. Gasoline contains cancer-causing additives, and diesel fuel contains some noxious components. Users should treat all such materials as if regulated, and give attention to the hazards of their use, including flammability, in crew trainings or analyses of hazards.

## DISCUSSION

Numerous experiments have shown that Alaska vegetation compares with Oregon species in structure, sensitivities to various products, and treatment phenologies. Glyphosate, hexazinone, and imazapyr are all products with good efficacy on a variety of species, and with good selectivity on desirable Alaska conifers when applied at the correct combination of dosage and season of application. All of these are also capable of damaging desirable moose browse, such as willows.

A few of the treatments for releasing or preparing spruce sites are very broad in spectrum of control despite their selectivity for spruce. These will be very useful when applied at the right time and dosage, but are capable of causing damage to crop trees if dosages are excessive or applied at the wrong time. In particular, glyphosate alone will control most deciduous shrubs and hardwoods without injuring spruce only if applied in fall and at application rates of about 1.1 pounds (1.5 quarts of product) per acre. Do not apply glyphosate in spring for any operations in Alaska because it is ineffective then, and will cause injury. Similarly, imazapyr will be most effective when glyphosate is used, and when applied in combination with glyphosate at very low dosages, such as 2 ounces/ac (4 fluid ounces of product), in which case, the rate of glyphosate may be reduced by a third.

Hexazinone is effective on a broad spectrum of species, such as grass, horsetail, and (in granular form) aspen. Hexazinone should normally be applied in spring, but if applied over spruce plugs, mortality can be expected because the potting medium will allow the herbicide to proceed directly to root tips. However, hexazinone applied in fall,

especially in mixture with glyphosate, is a very effective site prep treatment, and will not injure spruces planted the next spring (See Competition study in this series).

There are few places where phenoxy herbicides or triclopyr fit into the Alaska silviculture picture, in terms of the data presented here. However, we designed the experiments with relatively little insight that fall applications would be effective, and this is apparently not valid. Data from Maine (Newton et al. 1992a, 1992b) demonstrate that fall applications of triclopyr are not only effective on many deciduous northern species, they are also highly selective for spruces, balsam fir, and even white pine. Thus, there is incentive for further evaluation of both the ester and amine triclopyr products, both for spruce growth and browse enhancement.

The data from these experiments provide an adequate basis for most elements in establishing spruce, and for site preparation for birch under Alaska conditions. The mechanical treatments and fertilization provide a substantial basis for moose range improvement on accessible ground, and there are clearly opportunities for mixing spruce culture with those of willow and birch.

There is significant cost to the treatments evaluated. Whether the costs are justified by the growth will vary according to site quality and other management inputs. If the control of vegetation is restricted to a one-time application for site preparation or release, and the plantation (and its costs) is reflective of wide spacing and freedom from overhead competition, there is reasonable expectation of a decent return on investment. This is especially true if the Alaska law were to require success in establishing a particular crop, and where avoidance of the costs of failures must be considered a benefit of treatment.

The avoidance of reforestation liability may not be the major benefit of vegetation control. Our work in Oregon and initial patterns in Alaska indicate that there is an appreciable improvement in apparent site quality when seedlings' early years are characterized by freedom from overtopping and crowding. In Alaska, there is the additional factor of soil temperature, which may be improved to the advantage of a tree crop if there is no grass litter or deep accumulation of organic material on the soil. Decreased litter or organic matter may allow soil temperatures to increase earlier in the

spring, thus effectively increasing the potential growing season for crop species. Weeding, especially accompanied by fire, appears at least in the short run, to provide a major boost to spruce growth. Combining systemic weed control with a fall burn may provide a perfect opportunity to evaluate exactly what Alaska sites will provide in the way of silvicultural responses to management.

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# REFORESTATION AND VEGETATION MANAGEMENT IN CENTRAL ALASKA

## III. ENVIRONMENTAL EFFECTS OF VEGETATION MANAGEMENT

Michael Newton and Elizabeth C. Cole<sup>1</sup>

### INTRODUCTION

The existence of substantial competition during regeneration of all productive forest sites in Alaska will generally require some degree of control if one is to achieve full growth potential of conifers. The previous two sections of this series of reports outline both the reasons for weeding and the methods for achieving competition levels compatible with regeneration.

All vegetation control practices entail some sort of disturbance resulting in a decrease in occupation of forest sites by vegetation. This, in turn, frees soil resources to support spruce, birch, or other plants more desirable than the existing cover. The degree of disturbance is determined both by the degree of physical impacts and also by chemical interactions with plants.

The residual effects of treatment must remain long enough to assure dominance of desired species. There is concern that chemical residues after use of herbicides and use of large amounts of fossil fuels in clearing equipment pose some risks to wildlife and humans. Although there appears little toxicological reason for concern over the herbicides, those products are prominent in protests against forest weeding, and also in ballot initiatives to ban all chemicals in such uses.

Public concern over forest vegetation management is almost entirely focused on herbicides. Yet all forest vegetation management entails disturbance, most of which requires some use of fossil fuels or their derivatives and by-products. A comparative analysis of impacts of chemical and non-herbicidal practices is not possible without a detailed summary of both the exposure and toxicology of herbicides and the energetics, injury rates, and fuel hazards associated with mechanical and manual methods. We do not

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<sup>1</sup> Professor and Senior Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR 97331

have data specific to Alaska regarding health risks of vegetation management, but there are data from elsewhere (Newton and Dost 1984), which we will summarize. We also do not have human exposure data from Alaska herbicide experiments, but we do have analogous data from elsewhere, and such data are not specific to localities. The U. S. Forest Service has contracted a risk assessment (Labat-Anderson 1992) for herbicide use and non-chemical vegetation management in the five western regions of the National Forest System. These are based substantially on laboratory data and studies conducted in temperate forest regions. We present here a comprehensive body of data regarding dissipation of herbicides actually derived in a variety of Alaskan environments, and will describe deposition and degradation in terms that can be interpreted for wildlife impacts and influence on water and non-target plants.

## **METHODS**

We installed a series of experiments to obtain quantitative information regarding the persistence of herbicide residues after application in Alaskan forests. These plus laboratory data are combined to evaluate potential toxicological risks of using herbicides in high-latitude forests. Specifically, we were interested in how much of any given product lands on various targets so as to leave a residue, the presence of which can be interpreted as a component of forage or as contact exposure. Recognizing that residues in forage and soils decline with time, we inquired about the rates of decline in a variety of Alaskan environments so the potential cumulative exposure could be estimated. We needed to have these data in a form that would make possible the integration with a massive body of literature developed in temperate environments. Finally, we endeavored to provide some information about the upper extremes of herbicide movement with water toward fish-bearing streams, and to also determine the degree of vertical movement of herbicidal products in soils.

### **Experimental Approach**

Rate of deposition may be expressed in terms of actual products landing on the target area per unit area, as determined by rate of application. We have elaborated the



rates needed for adequate control in Section II of this series. The concentration in soil is a function of rate applied and density of soil, and represents the initial condition for degradation. In Alaska forest soils, an application of one pound of a product on an acre leads to an average concentration in the surface six inches of soil ranging from 0.6 to 1.0 part of herbicide per million parts of soil. This concentration is not only low, it is isolated from humans and wildlife unless it is picked up by vegetation or moves into water in quantities great enough to cause toxic harm. We therefore determined the rates at which these chemicals degrade in place, the rates at which they might be found in plants as the result either of treatment or uptake from soil residues, and whether movement might be occurring at rates capable of causing metabolic harm to vegetation or other non-target species.

Four groups of chemical products appear to have potential utility for forest vegetation management in Alaska. We evaluated a representative from each group as follows:

<u>Chemical(group)</u>	<u>Use Area</u>
Hexazinone (soil residual)	Herb, aspen type
Triclopyr (growth regulator)	Aspen, alder
Glyphosate (systemic, non residual)	All
Imazapyr (systemic, residual)	Injection, complex woody cover

Hexazinone is a soil-active inhibitor of photosynthesis. Triclopyr, the representative of growth regulators, is virtually inactive in soil, but influences cell wall metabolism after uptake by foliage. Glyphosate acts in plants by inhibiting formation of two essential aromatic amino acids after being taken up through foliage. Imazapyr inhibits formation of two aliphatic essential amino acids and is taken up by both foliage and roots. None of the above products has primary metabolic activity in animals. They are of concern to wildlife and humans only if concentrations in the environment were very high, and if they could somehow be transferred in large amounts from where they are deposited to animal life. Thus, we were interested in whether the residues were somehow

excessively high, if they were mobile or dislodgeable, and if they appeared in the food supply via the soil.

### **Soils and vegetation**

The four products were evaluated in four distinct environments described below. We installed triplicate treatment plots with each product in each of the environments. We selected sites where it would be logical to use some form of vegetation management, and indeed these were sites near where we had vegetation control experiments but far enough distant so that there could be no cross-contamination.

The four sites were focused in two areas, in Bonanza Creek Experimental Forest, west of Fairbanks, and at Windy Bay, on the southern tip of the Kenai Peninsula. At Bonanza Creek, we treated plots on a warm southern exposure at about 1,000 feet elevation, where soils were a deep loess silt-loam with 10-15% slope, and also on the nearby Tanana River floodplain where soils were deep silt loam but cold and flat, with pockets of permanent frost. Annual precipitation is about 11 inches, and the only significant surface runoff occurs during spring snowmelt. At Windy Bay, a climate with approximately 90 inches of precipitation and shallow (6-12 inches) ash-derived soils over talus/brecchia rocks, we treated soils on 30-70 percent slopes, and also on flat areas almost at sea level. The Bonanza Creek climate is dry and warm in summer with very cold winters. The Windy Bay climate is wet year-round, with heavy rains in late summer. Perennial streams are ubiquitous. Summers are cool and winters cold but not as frigid as are the interior sites.

### ***Application***

At each site, three 12 x 72-foot plots were treated with each product with rates of application equivalent to twice the rates normally used to treat vegetation in Alaska. We used high rates of application for two reasons. First, it is prudent to have information relevant to "worst cases". Of greater scientific importance, we anticipated residue levels close to the limits of detection in some products after some dissipation, and needed assurance that we could study rates of dissipation accurately beyond the normal range of

persistence. Reliability of detection and quantification of dissipation rates is greatest when there is a substantial margin above the detection limit. This degree of excess is not known to bias proportional rates of dissipation, but certainly increases the length of time one may reasonably expect to detect some residues to beyond the normal range. The quantities found must be divided in half to ascertain the expected residues in each environment and their dissipation rates in normal use.

Actual rates applied were, for hexazinone, 2.0 pounds active ingredient (a.i.) per acre at Bonanza Creek, and 2.5 pounds per acre at Windy Bay; triclopyr 2.0 pounds acid equivalent (a.e.) per acre both sites; glyphosate, 1.5 pounds a.e. per acre at Bonanza Creek and 2.0 pounds per acre at Windy Bay; and imazapyr 0.25 pound a.e. per acre both sites. Each was applied with a hand-held boom-type sprayer in water dilutions so that the active herbicide was distributed in 12 gallons of water per acre, a volume similar to operational rates.

Glyphosate was applied in late August. The other products were applied in late May, reflecting times when these products were expected to be used.

### *Sampling*

Herbicide residues in soil are decreased through time by several processes. The principal degradation mechanism is microbial. Soil bacteria and fungi utilize organic molecules for their energy sources in a manner similar to their roles in decomposition of naturally occurring organic matter. Because microbial activity rates are affected by temperature and water availability, we recorded temperature and moisture content of soils during all growing-season intervals between serial samplings.

Samples of soil and vegetation were taken for analysis at intervals during the fourteen months following treatment, and also before treatment. No samples were taken during the winter when soil was frozen.

Soils were sampled by removing triplicate cylindrical samples in each plot to depths of 0-6 inches and 6-18 inches, reflecting whether movement occurs down the soil profile under the influence of water. An additional sample was drawn for gravimetric determination of water content. All soil residue samples were taken with a

“Contamination-Free” extraction tool that collected samples in plastic tubes that could be sealed without the operator touching the sample.

Soil temperature was recorded continuously during the growing season at both Windy Bay and Bonanza Creek by an Omnidata® electronic data recorder. Precipitation was recorded in standard rain gauges at both locations and checked regularly by local cooperators.

Vegetation was collected only from the upland plots, because deposition is not affected by differences between upland and alluvial site conditions. At each date of soil sampling, approximately one pound of vegetation, largely from plants likely to be used as moose browse, such as willows, elderberry, *Viburnum*, aspen, and alder, and occasionally grass, was collected from each plot. In cases where treatment had killed most cover, samples were filled out with whatever green plants were available. When possible, samples were frozen within 5 hours after collection to halt biological degradation processes, and remained frozen until analyzed at the Oregon State University Department of Agricultural Chemistry, Corvallis. Because of the remote location of Windy Bay, some samples could not be frozen the same day as collection. These samples were kept at below refrigerator temperature until they could be frozen.

### **Movement in water**

Previous experiments in temperate climates (Newton et al. 1984, 1990, 1994) have shown that mobility of glyphosate and triclopyr is negligible in soil, but there has been evidence that hexazinone can move short distances toward depressions in quantities sufficient to cause conifer injury, hence potentially to appear in water (Newton, M.. Unpublished observations). We conducted an experiment at Windy Bay to determine whether leaching by rainfall would occur in amounts sufficient to cause damage to plants or fish.

We selected conditions for this experiment representative of the worst possible case for movement in water. Specifically, we established triplicate 2-acre plots with the long axis upslope (Figure 3.1) and treated them with hexazinone at a rate of 2.5 pounds per acre in early June. The site was characteristic of recent clearcuts on steep ground (60-

70% slopes) in the Sitka spruce zone. The ground was occupied by dense grass, with some fireweed and scattered clumps of elderberry. All plots were situated 100' above a nearly vertical cutbank above a logging road. The road ditch contained a small perennial stream that collected from numerous springs near the treatment site and emptied into Windy Bay without entering a larger fish-bearing stream.

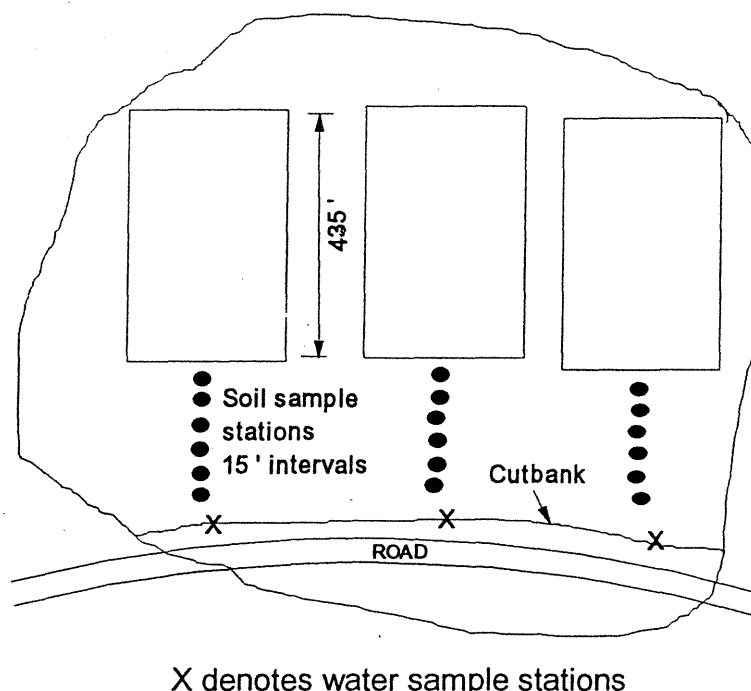


Figure 3.1 Schematic diagram of plot layout for Windy Bay Movement in Water Study.

On the slope between the treated plots and the roadbank, we established sampling stations 15' apart, starting 15 feet downslope from each plot. Thus, there were six sample points below each plot, at 15, 30, 45, 60, 75, and 90 feet downslope from the treated plots, from which we took soil samples during the year following treatment. We also identified water seepage points on the cutbank that would reflect levels of contamination in the water moving downslope through soil, and made small collector basins above the ditch from which water samples were taken at each date of soil sampling. Determination of hexazinone in soil samples was an indication of how far the herbicide had moved below the steep treatment units. The amount appearing in seepage water represents the most concentrated level of input to streams before any dilution. Existence of sensitive grass

species provided a clear boundary across which movement of biologically important residues in surface soils would have been visible.

## RESULTS

Analyses were done by the Oregon State University Department of Agricultural Chemistry with techniques adapted for the soils and vegetation from these experiments. Analyses were corrected to adjust for naturally occurring materials that interfere with herbicide determinations.

### Soil residues

Figure 3.2 shows proportional dissipation of each herbicide applied at Windy Bay, based on fraction of initial concentrations of each herbicide remaining at intervals after application, hence the relative rates of dissipation from soil. The curves are shown for pooled upland and river-bottom sites because they were similar. Not shown are the data from subsoils, because they represent a minor fraction of the concentrations in the surface six inches (less than 15% of concentrations in surface soils). For individual products, where applicable, we will report the absolute percentage of surface residue that appeared to have moved into the 6-18-inch depth zone. We report the absolute amount instead of concentration in the deeper layer, because concentration is diluted by the greater volume of soil in the 6-18-inch zone compared to 0-6-inch zone.

All products demonstrated moderate rates of degradation in soil during the seasons warm enough for microbial activity. At Windy Bay, the soil temperatures ranged from 55-63F° during the 120 days after treatment. Combined with abundant moisture, this is a condition highly favorable for both degradation and leaching of the more mobile products.

Figure 3.2 illustrates the same general patterns for Bonanza Creek as for Windy Bay. Note that rates of dissipation are marginally slower on the site with little precipitation, despite soil temperatures that ranged up to 65F° and adequate moisture for rapid microbial activity.

Figure 3.2 reflects the general patterns of dissipation of the four herbicides. It does not provide the details nor the data points. It describes the way concentrations in the

soil decrease from an initial level of contamination, and provides the basis for estimation of actual residues at any given time for the general run of upland and riverbottom sites of reasonable productive capacity. The lower portions of each curve cannot be interpreted quantitatively. They represent "not found at the limit of detection" and may be between zero and the lowest detectable trace, which is far below any known biological sensitivity. Details of the data are available from the authors.

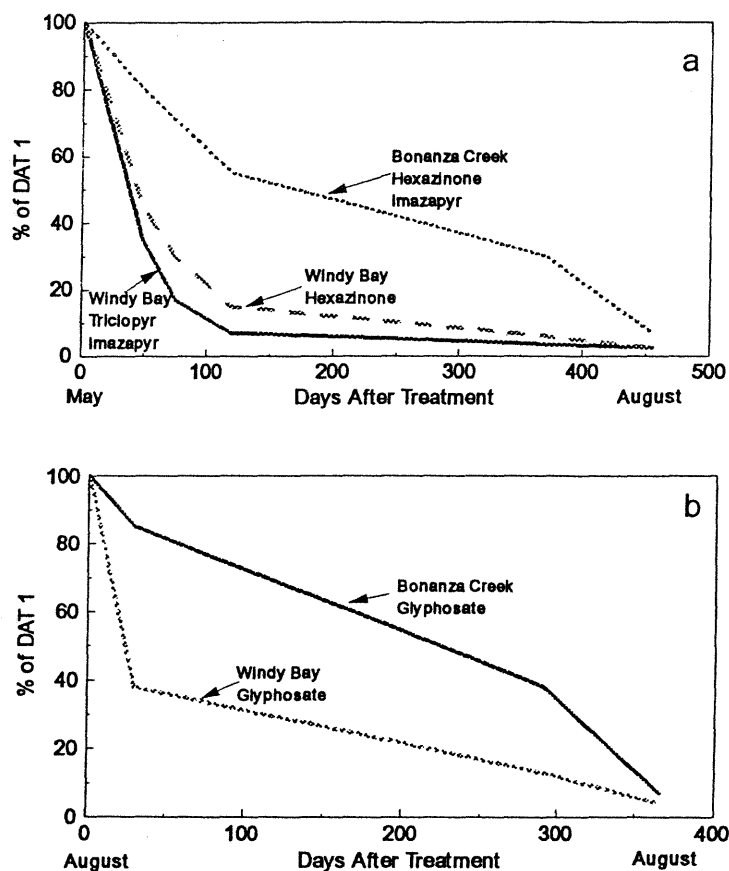


Figure 3.2. Schematic patterns of dissipation from a) hexazinone, imazapyr, and triclopyr and b) glyphosate at Bonanza Creek and Windy Bay.

There were some differences in the way products dissipated. The following discussion outlines the principal ways in which we would explain those differences.

### *Triclopyr*

Triclopyr dissipated rapidly from surface soil at all sites, but most rapidly from the high-rainfall Windy Bay region. Surface soils from both upland and riverbottom sites at Windy Bay showed residues at about one fifth the initial residue level by 49 days after treatment, or an approximate half-life in situ of somewhat less than 25 days. Surface residues were non-detectable by 120 days after treatment. Residues were found in subsoils at up to five percent those of surface soil 49 days after treatment, decreasing mostly to non-detectable at 120 days, with one sample above the lower limit of detection. At Bonanza Creek, the warmer and drier, but more northerly site, dissipation was somewhat slower, and residues were detectable at the onset of winter, after which they disappeared. Half-lives of both upland and riverbottom residues at Bonanza Creek were slightly over 50 days in surface soil. Twelve to 26 percent of the surface residues appeared in subsoil. Triclopyr degraded at the same proportional rates in both soil layers. One subsoil sample contained marginally detectable triclopyr after 450 days.

### *Hexazinone*

Hexazinone had the greatest tendency to move into the lower soil zone. At Windy Bay, surface soil concentration decreased to 30 to 60 percent of initial concentrations by 49 days after application, and 0 to 15 percent of initial concentrations by 120 days, reflecting a half-life of about 30 to 50 days. Movement into subsoil accounted for some of the disappearance, and the levels appearing in subsoil at 120 days accounted for about 8 to 30 percent of the initial deposit. Thus, half-lives are somewhat longer than predicted from surface residues alone. The finding that residues in both surface and subsoil were very close to the detection limit or below it by 450 days after treatment provides evidence that the material is being degraded as well as being moved into the subsoil.

Hexazinone residue patterns at Bonanza Creek reinforced the finding that degradation is occurring. Even without surplus precipitation, (hence negligible leaching) residues decreased through the growing season, the following fall and spring, and nearly disappeared altogether the following summer. There was evidence of movement below the surface six inches, but residues were always less than in surface soils by a factor of at



least five. An estimate of half-life in surface soil approaches 120 days in this environment, or somewhat more after allowing for residues moving into the subsoil. However, it must be acknowledged that half-life estimates are necessarily approximate minimum values on sites where residues may have leached beyond reach. That condition was assuredly reached at Windy Bay, and although unlikely at Bonanza Creek, we do not have positive evidence that we accounted for all residues.

### *Imazapyr*

Imazapyr dissipated moderately rapidly at Windy Bay, but more slowly at Bonanza Creek. Again, patterns at upland and riverbottom sites were similar, and residues were approaching detection limits 120 days after application. Estimated half-life is on the order of 50 days or less. Because no residues were found to have moved below the surface six inches, we are confident that these data reflect the real degradation rate of imazapyr.

Dissipation of imazapyr at Bonanza Creek is difficult to interpret, owing to one erratic data point. Moreover, concentrations were so low in all soil samples that a precise determination of rate of loss was unachievable. However, the negligible mammalian toxicity and immobility of this product, coupled with its low rate of application and positive evidence of its disappearance suggest that the precision of the above estimates provides a substantial margin of safety.

### *Glyphosate*

The application of glyphosate was followed by a somewhat different sampling sequence because of fall application, and non-accessability during winter. We observed at the wet Windy Bay site that there was a rapid decrease in soil residues during the fall after treatment, stable conditions during winter, and disappearance the following summer (Figure 3.2b). From fall application, the drop in residues to about 40 percent in 30 days suggests a half-life of about 25 days or less during the growing season. Unlike previous experience with glyphosate (Newton et al. 1984), we detected some movement into subsoil, complicating the estimation of half-life. The decrease in residues in both layers to non-detectable in all but one sample after one year demonstrates that disappearance will

occur with reasonable rapidity; if the year-end residue were at two percent of the initial application, and no degradation had occurred during six months of winter, half-life would still be less than 45 days, or similar to the pattern observed in the first sampling interval.

As with the other chemicals, dissipation of glyphosate was slightly slower at Bonanza Creek than at Windy Bay, with residue levels dropping to about 50 percent in 30 days after application and decreasing to near detection limits by 360 days. Some residues appeared in the subsoil (0 to 23 percent of surface residues), and all but one sample was below the level of detection by 300 days after application.

### *Summary of soil dissipation*

Both downward mobility and rate of dissipation were related to differences in rainfall between sites, but not to differences between upland and riverbottom environments. Soil temperatures were similar between interior and coastal sites, hence rates of dissipation apparently differed primarily because of moisture. Soil temperatures on all sites were similar to those observed in Oregon during the period of available soil moisture for tree growth, leading to confidence in use of temperate data in extending these conclusions.

The movement of residues below six inches was expected for triclopyr and hexazinone, but not for glyphosate. There were no previous data for imazapyr of this type, but the pattern of non-movement is now showing up in analogous Oregon experiments.

### **Vegetation**

Vegetation contained expected residues immediately after application (Table 3.1, Figure 3.3). These dropped very rapidly during the weeks immediately following treatment, whether the products were those exclusively taken up by foliage or through soil. All products except triclopyr reached non-detectable concentrations before the first resampling took place at 30-49 days after treatment. Triclopyr fell to the detection limit at Windy Bay before the first sampling, but persisted longer in Bonanza Creek. Even at Bonanza Creek, residues were close to the detection limit by the end of summer.

Table 3.1 Herbicide residues in vegetation immediately following application (initial concentrations).

Herbicide	Windy Bay	Fairbanks	% Recovery
Hexazinone	290 ppm	335 ppm	87.5
Glyphosate	410 ppm	59 ppm	74.7
Imazapyr	21 ppm	16 ppm	93.0
Triclopyr	310 ppm	392 ppm	68.4

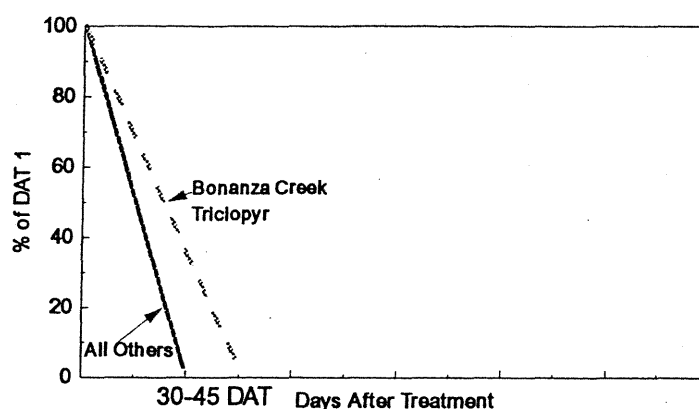


Figure 3.3 Schematic patterns of dissipation of hexazinone, glyphosate, imazapyr, and triclopyr residues in vegetation at Bonanza Creek and Windy Bay, based on percentages of initial residues.

#### Lateral movement of hexazinone in water

Hexazinone moved downslope in an apparently short-lived pulse during a period of high-intensity rains. At least 11 inches of rain fell in the first 30 days after application. Attempts to revisit the site for the 45 days after treatment (DAT) sample failed owing to stormy weather and uncertain flying conditions. By the time we could sample, at 76 DAT, a pulse of residue had moved in soil water through the 100-foot untreated zone from the treated plots so that some hexazinone was appearing in seepage water at the cutbank 100 feet below. At DAT 76, the pulse had moved so that the highest concentration in soil was 90 feet downslope from the edge of the treated plots (Figure 3.4). Furthermore, the narrow nature of the pulse was such that the samples closest to the treated area were either at non-detectable levels or nearly so. At this time, seepage water showed an

average concentration of .011 part per million. At 120 DAT, concentrations at all points had decreased substantially, but the water draining the slope still contained detectable traces of hexazinone until about 450 days following treatment.

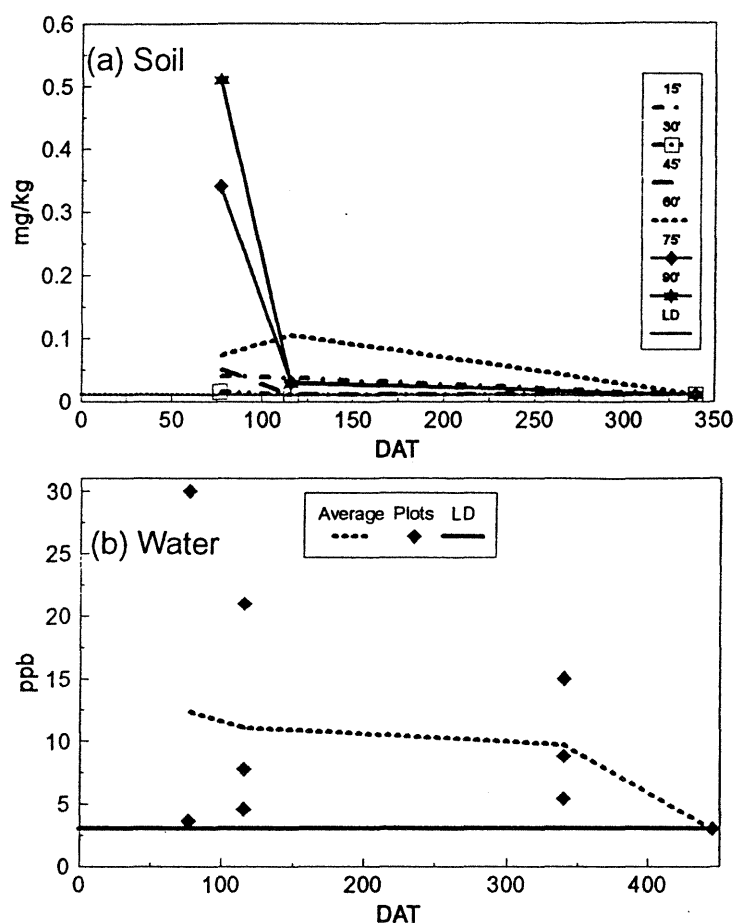


Figure 3.4 Data from the lateral movement study at Windy Bay, showing the movement of hexazinone downslope in (a) soil and (b) water. LD denotes the level of detection.

It was possible to make a crude estimate of the amount of hexazinone moving off-site in water. A total of 15 pounds of hexazinone was applied to these three plots. The seepage water we collected during 450 days after treatment provided a consistent periodic measure of how much was leaving the site as a function of the amount of water running off the six treated acres. If runoff in this wet climate during the ensuing year were 80 inches (assuming 10 inches evapotranspiration), at an average concentration of .01 ppm (10 ppb), the total amount of hexazinone appearing in the water from these plots would amount to roughly 7 percent of the total applied, and this amount would be distributed

over a full year. For this estimate, we must assume that the concentration in the water was representative of all water leaving the plots, and that water from the plots did not include any other water. In view of drainage patterns and weakly convex nature of land in the plots along the upper reaches of their long axes, this appears a reasonable assumption.

### INTERPRETATION

Concentrations in vegetation/forage found immediately after treatment are consistent with those observed elsewhere (Newton, et al. 1984, 1990, 1994) and decreased similarly. Rates of dissipation are rapid enough so that accumulation of residues in animals could not occur, as reported by Newton et al. (1984), for products with high water solubility, a property of all these products. They reported that glyphosate, a product with low affinity for fat, was present in much lower concentrations in body tissues, in general, than were present in the gut. Gut levels were much lower than concentrations found in vegetation. Furthermore, as residues in vegetation decreased with time, quantities found in animal viscera and other body parts declined proportionally, but at much lower concentrations than found in the general environment. Carnivores had lower body concentrations than herbivores. Between foraging behavior and rapid elimination of herbicides, along with declining residues in the food supply, animals whose habitats are sprayed have much lower exposure rates than would be predicted from residues in their environments.

The slight extension of the triclopyr residues at Bonanza Creek is postulated as the result of some desiccated material from aspen suckers in the vegetation samples. The onset of dry conditions would stop microbial decomposition. The other products did not produce the foliage desiccant symptoms observed for triclopyr. Studies from southwestern Oregon with evergreen shrubs (Newton et al. 1990) showed that moderate levels of inert residues remained in dead material until deposited in litter, where residues degraded rapidly. When vegetation dies and dries, conditions for microbial degradation are poor, whereas residues in green vegetation, i.e. suitable for forage, would tend to be transient, rapidly decreasing in quantity, and in a form not retained by foraging animals.

Residues of products taken up by roots from soil could have some inhibitory effect on plants. Hexazinone residues remain at biologically active (for photosynthetic plants) levels during the remainder of the growing season after spring application, and possibly contributing to second-year control of sensitive plants. These residues are part of the reason for the efficacy of this product for control of vegetation with proliferation of roots in surface soils, such as grasses. Imazapyr residues can be taken up by higher plants to a degree, but their lack of mobility suggests that their availability in the soil solution is limited. Glyphosate and triclopyr are neither readily mobile nor readily taken up by roots, hence they represent no measurable toxicological risk to non-target species as residues dissipate in the soil.

Mobility of hexazinone was demonstrated in consistently detectable levels. During the summer following application, a pulse of hexazinone moved downslope from the treated area. The appearance of hexazinone in the soil sequences showed rapid but one-time movement as a wave, or pulse. Persistence of the pulse was no more than a month or two, followed by disappearance of mobile hexazinone from soil. At no time was there sufficient hexazinone in soil downslope from the treated areas to show up as symptoms in sensitive vegetation, despite substantial control within the treated area. Yet a very low level of hexazinone continued to appear in water for almost a year. This suggests that the longer-lasting source in the seepage water came from a slightly deeper pool of water out of reach of roots, not subject to the degrading processes occurring in the surface soil, and appearing gradually as it was being displaced by continued rainfall. There was substantial agreement between our over-all hexazinone dissipation data and patterns documented in northern Alberta by Sidhu and Feng (1990). Whereas they reported gradual dissipation, mostly by microbial degradation, they observed little or no deep percolation, hence unlikely transport to deep groundwater. They used rates of application that bracketed our studies on sites with moisture conditions similar to those at Bonanza Creek. Our data show somewhat more rapid dissipation, especially at Windy Bay. They did not see evidence of deep percolation, but they did not have the leaching pressure of Windy Bay climate and soil. Feng (1987) also reported no evidence of detectable movement 66 feet downslope on a 5-10% gradient. Neary (1983) did not observe hexazinone in

groundwater and springflow beyond 66 feet from a treated area, but Neary et al. (1983, 1986) reported 0.53% of hexazinone applied as large "gridballs" appearing in streams and baseflow in forests of southeastern U.S., in the first 13 months after application. Our patterns in water showed higher concentrations and off-site delivery than other studies we are aware of, and were under conditions leading to maximum movement. Thus, our estimate that these data represent a worst-case picture seems to be reasonable.

The maximum concentration seeping into the road ditch was .030 part per million. Even if such a concentration were to appear in a fish-bearing stream for a significant period of exposure, it is well below concentrations ever reported to have detectable metabolic effects in fish or other water users (Newton and Dost 1984). Hexazinone is a water-soluble product that is not known to accumulate in animals, including fish. We would not expect streamwater with this level of residue to accumulate residue levels harmful either to the fish or to consumers of fish. The Labat-Anderson (1992) summary of available data indicated that worst-case aquatic concentrations in streams of nearly 1,000 times levels we observed (i.e. 7,356 parts per billion) were well below half the median lethal concentration for fish or aquatic invertebrates. Even so, the seepage we observed was diluted many times before entering any waters large enough to bear fish.

Because contamination of water is of paramount interest with respect to the Alaska fishery, we offer some estimates of actual probable limits on stream contamination resulting from normal use of hexazinone. The amount of hexazinone expected to appear in any fish-bearing stream would be proportional to the fraction of a watershed treated, after adjusting to rate of application. Recalling that our experiments were worst-case situations by virtue of slope, soil permeability, rate of application and rainfall, we would expect actual concentrations to be much less at the cutbank in any normal operations. Nevertheless, supposing that an operator applied 1.5 pounds per acre to five percent of a watershed with a fish-bearing stream, the estimate of maximum concentration in the stream would be adjusted downward from our maximum seepage as follows:

Adjust for rate of application  $2.5/1.5 =$  a factor of 0.6.

Adjust for percentage of area treated: .05

Expected worst contamination in the main stream draining a basin of which five percent was treated, and based on our *worst* observation, would be  $.030 \text{ ppm} \times .6 \times .05 = .0009 \text{ ppm}$ . Based on *average* concentration observed, the streamwater concentration would trend downward from  $.0003 \text{ ppm}$ , less than a thousandth of the lowest concentration known to affect fish biology or stream productivity (Labat-Anderson 1992).

The expected worst-case contamination is not only non-detectable under today's analytical methods, but it has no meaning in terms of bioaccumulation or direct toxic effects on any known inhabitant or user of water. Indeed, at this level, concentrations of naturally occurring chemicals would be of far greater concern, and be in far greater quantities.

Whether as residues in soil, vegetation or water, the remnants of a herbicide application in Alaska's forests have negligible impact on the environment other than to change the composition of vegetation. This change is more or less permanent, depending on goals of the land owner. The very purpose of treatment is to create an environment compatible with the needs of species of plants one desires to occupy the site for a matter of decades or centuries. These plants need freedom from competition for no more than one to three years. Herbicides applied at rates of application below those evaluated here are capable of achieving this without physical disturbance, erosion effect, or major use of fossil fuels.

For perspective, removal of vegetation by machine relies on physical disturbance for killing or displacing competing plants. When moving sod or sprouting woody plants off-site, there is inevitably some loss of soil and/or creation of erosion channels. Thorough use of machinery for vegetation control exposes soil to impacts of raindrops, leading to movement, development of erosion pavements, and movement of silt into streams. Whereas this amount may turn out to be negligible with careful use, the overall impact will be greater than that of vegetation control chemicals, as nearly as can be determined.

Energy use of mechanical methods is also far greater than when using chemicals. The petroleum equivalent of the herbicides normally used for forest weeding ranges from one to two gallons per acre, including synthesis and aerial or other methods of low-



volume application. For mechanical control, some 20-50 gallons of diesel fuel per acre are used, plus whatever energy is used to manufacture and transport the equipment. The on-site dissipation of fuels and combustion products entails approximately 10 pounds of toxic pollutants per gallon of fuel used. Unlike the herbicidal products, these materials are complex in composition, and include products that cause cancer and numerous acute toxic symptoms when exposed in significant quantities. Thus, mechanical means are not strictly non-chemical, nor are they safe from accidental exposure to their by-products or risk of serious personal injury. Accidents are a major additional health risk when using certain mechanical and manual methods. Newton and Dost (1984) summarized two years of occupational accidents with manual removal of shrubs in Oregon, with the finding that frequency of debilitating injury was very high and total health risk was orders of magnitude greater than when applying herbicides by aircraft.

The above comparison of impacts of chemical versus non-chemical methods of competition control reflects on the risk of evaluating one set of practices without analogous comparison with alternatives. There are very good data on safety of herbicides. The data for "non-chemical" methods is neither strong nor encouraging. The data for manual treatment are somewhat better than for heavy equipment, but they illustrate that manual treatment is likely the most hazardous of all methods (Newton and Dost 1984).

All the above notwithstanding, the very purpose of vegetation control techniques is to achieve a land management objective. There are places where mechanical and chemical vegetation management tools are effective, but we know of no circumstances relevant to Alaska where manual methods are effective, safe or economically feasible methods of reaching reforestation success. Having the desirable impact at reasonable cost and within the acceptable limits of safety is the purpose of all weeding treatments. The above safety information should facilitate the choice of methods.

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Figure 1. Location of study sites for the Alaska Science and Technology Foundation (ASTF) white spruce reforestation study.

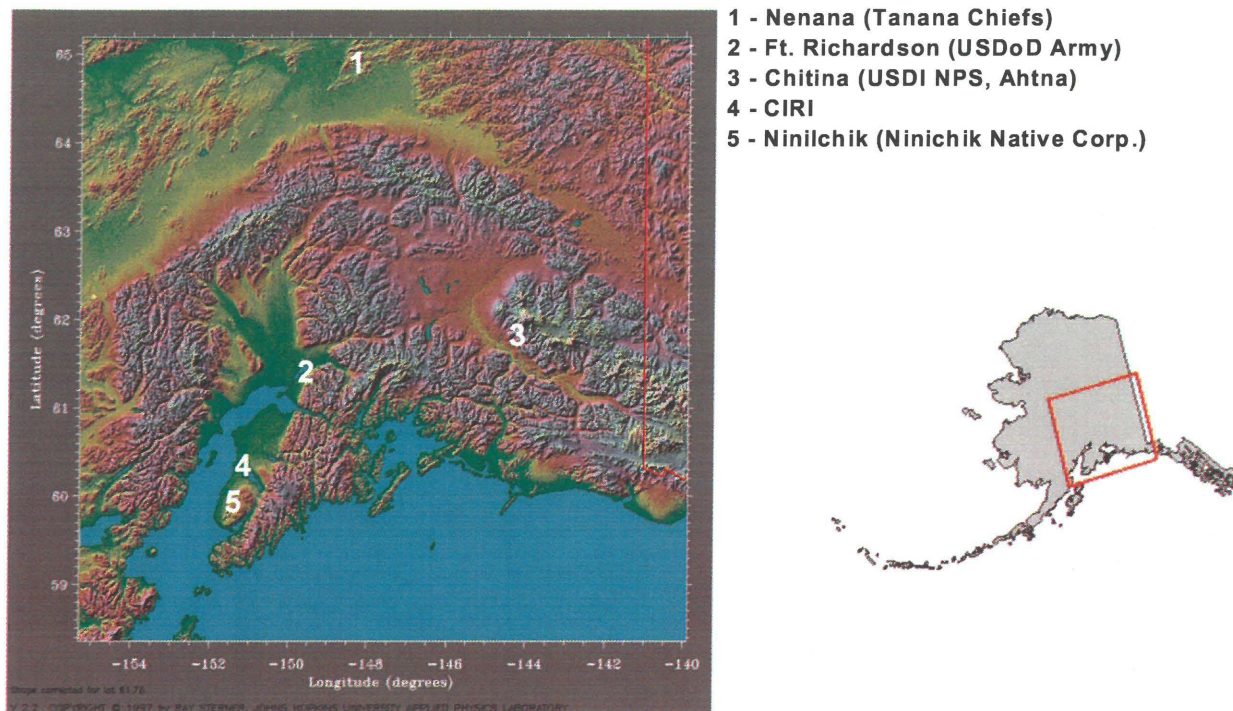


Figure 2. Typical plot design for the ASTF white spruce reforestation study at each location, used at both New and Old sites

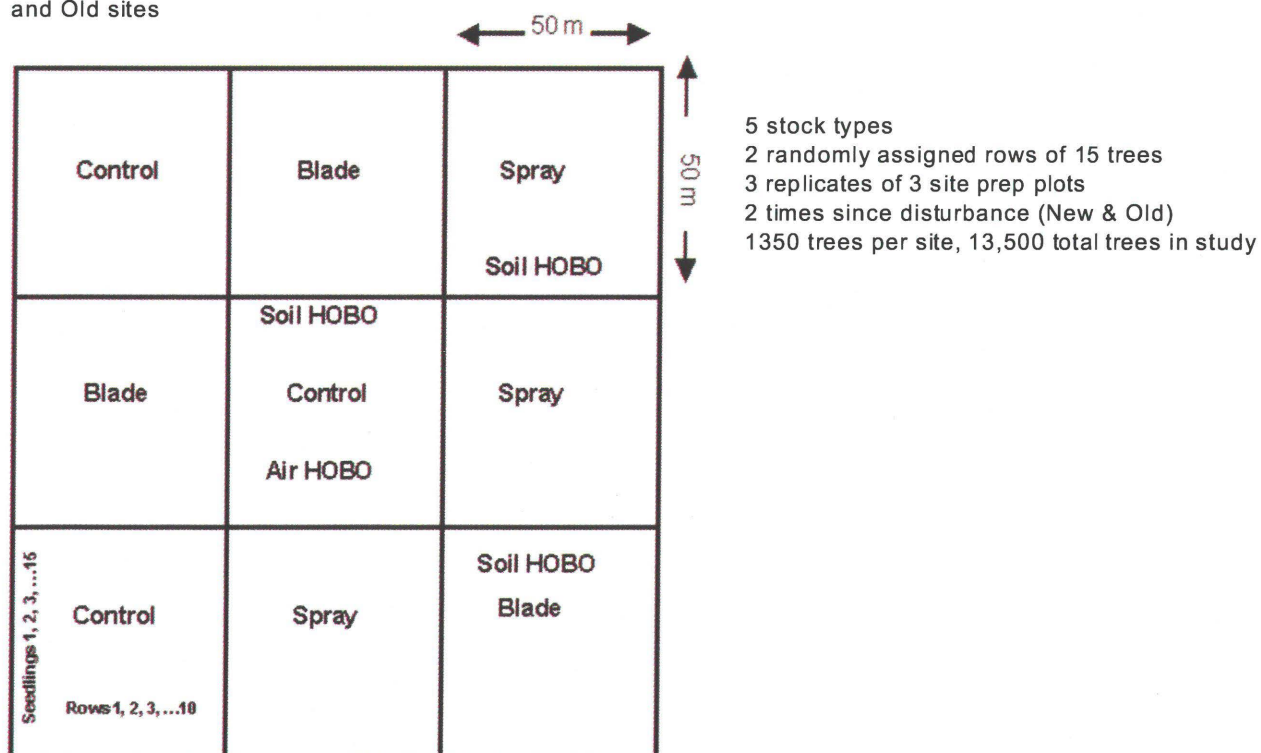


Figure 3. Fort Richardson Alaska Science and Technology Foundation installation, 3-year-old site at Firewood Unit, cut 1991-1994 and planted spring 1997.

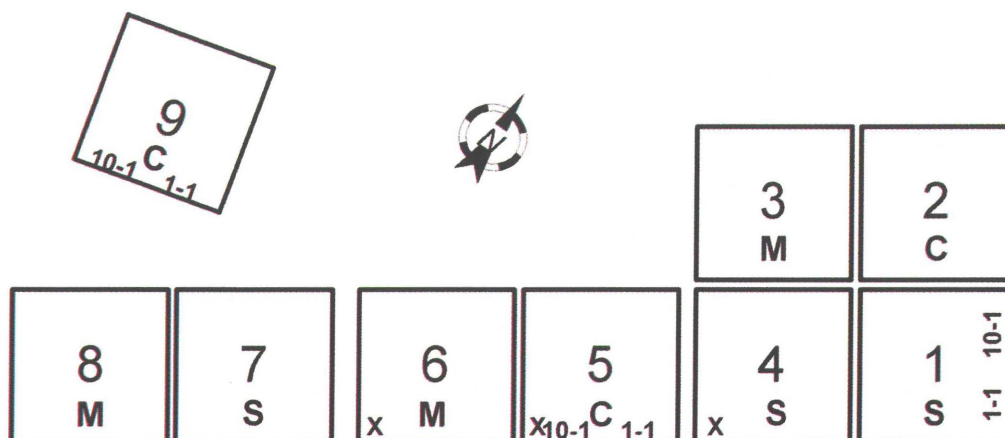


Table 1. Stock types for the Alaska Science and Technology Foundation white spruce competition study

Flag color	Seedling source	Stock type
Pink	Alaska State Nursery	Plug+1; container stock for 1 year, and then transplanted for 1 year in a nursery field
Red	Alaska State Nursery	Plug+2; container stock for 1 year and then were transplanted for 2 years in a field nursery
Orange	Pelton	Plug; 1-year-old container stock
Yellow	Silvaseed	Plug; 1-year-old container stock
Blue	Silvaseed	Plug+1; container stock for 1 year, and then transplanted for 1 year in a nursery field

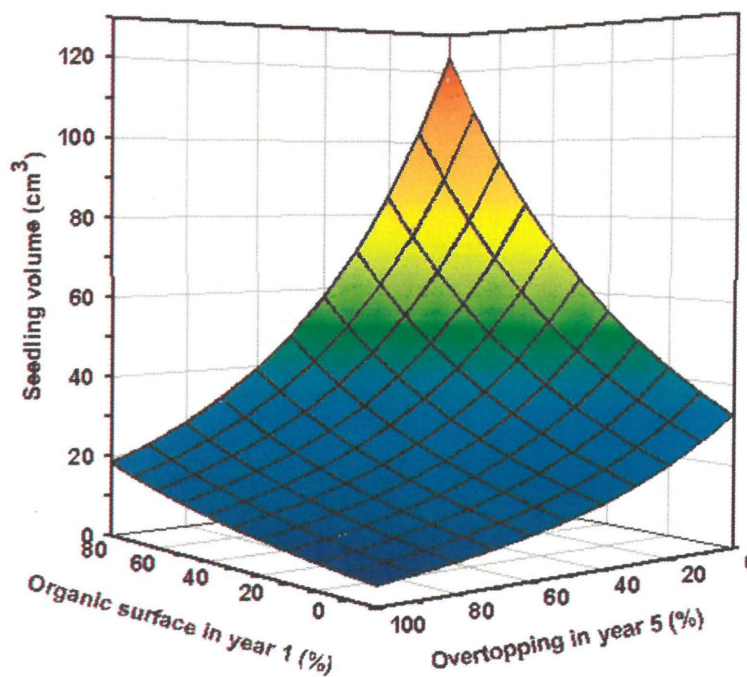


Figure 4. Response surface relating seedling stem volume at the Fort Richardson Old site to cover of organic matter, down woody slash, and moss within a 0.5 meter radius one year after planting, and overtopping of competing vegetation in the fifth year. Initial seedling stem volume set to 2.98 cm<sup>3</sup>.

Figure. 5. Fort Richardson competition study layout in Firewood unit, cut 1990-1991, planted 1992.

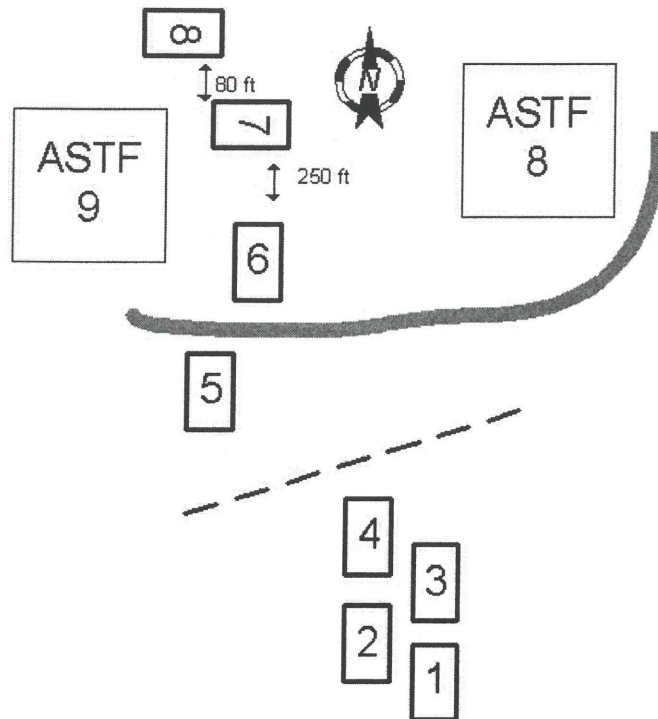


Table 2. Treatment randomization and design, Fort Richardson competition study, Firewood unit, blocks 1, 2..

Plot	Treatment	Description
1, 6	Control	Untreated
2, 5	Weed-free	Site prep broadcast + direct application of glyphosate for 5 years
4, 8	Site prep.	Broadcast hexazinone + glyphosate fall before planting
3, 7	Release	Broadcast granular hexazinone after planting

Table 3. Year 10 tree height and basal diameter for three installations of the white spruce competition study at Fort Richardson.

Treatment	Bulldog	Davis	Firewood	Bulldog	Davis	Firewood
	Total tree height (cm)			Basal diameter (mm)		
Untreated	92	129	208	14.4	18.4	33.4
Site Prep	133	181	234	22.4	29.3	40.2
Release	128	177	198	21.4	27.6	32.6
Weed-free	259	283	318	54.5	57.5	65.6



Figure. 6. Response surface relating basal diameter in year 10 at the Fort Richardson white spruce competition units to percent overtopping in year 5 and percent competing cover in year 5. Symbols represent individual trees at Bulldog (●), Davis (○), and Firewood (▼).

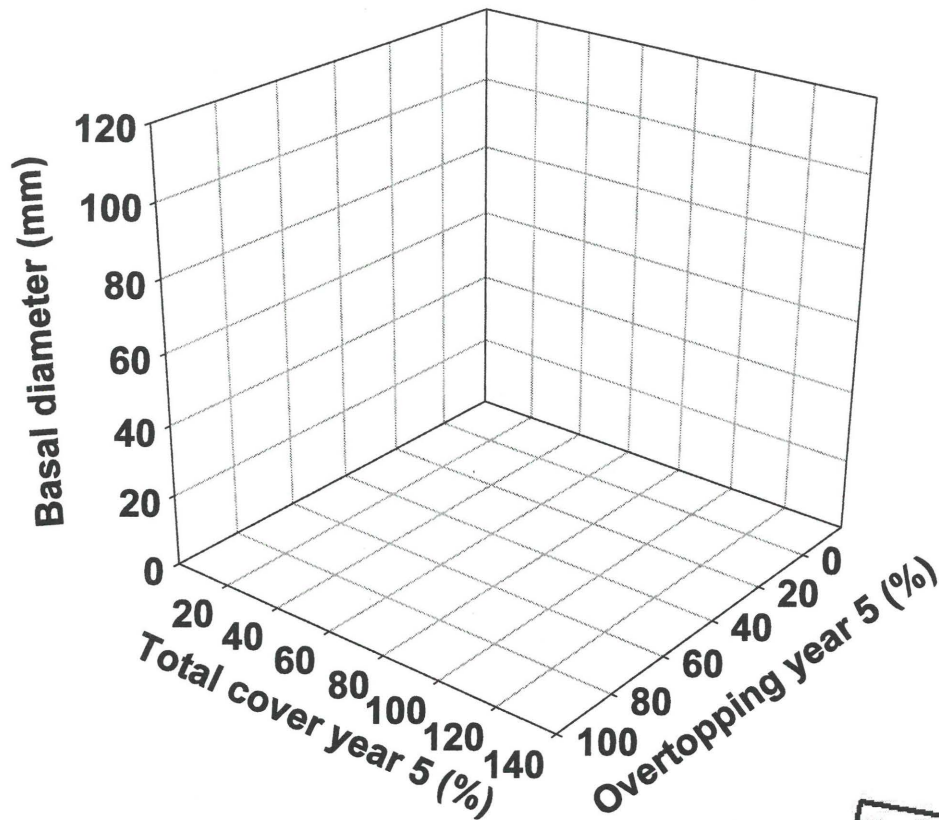


Figure. 7. Fort Richardson ASTF installation, 1-year-old site at Firewood Unit, cut 1996 and planted spring 1997.

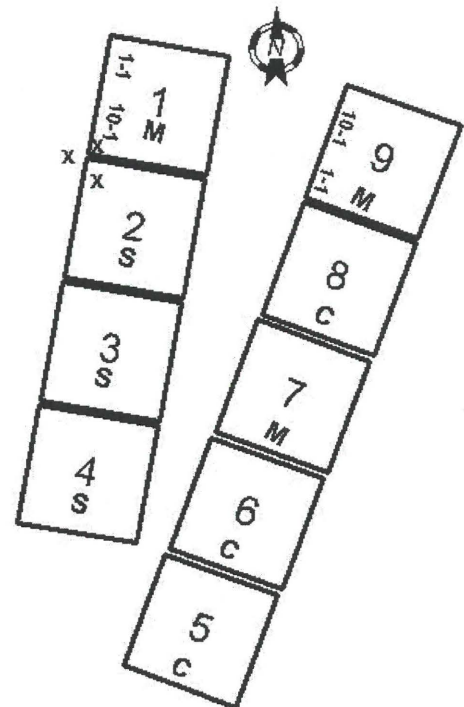


Figure 8. Seedling volume over five years for five stock types and three site preparation treatments at the Tanana New ASTF site.

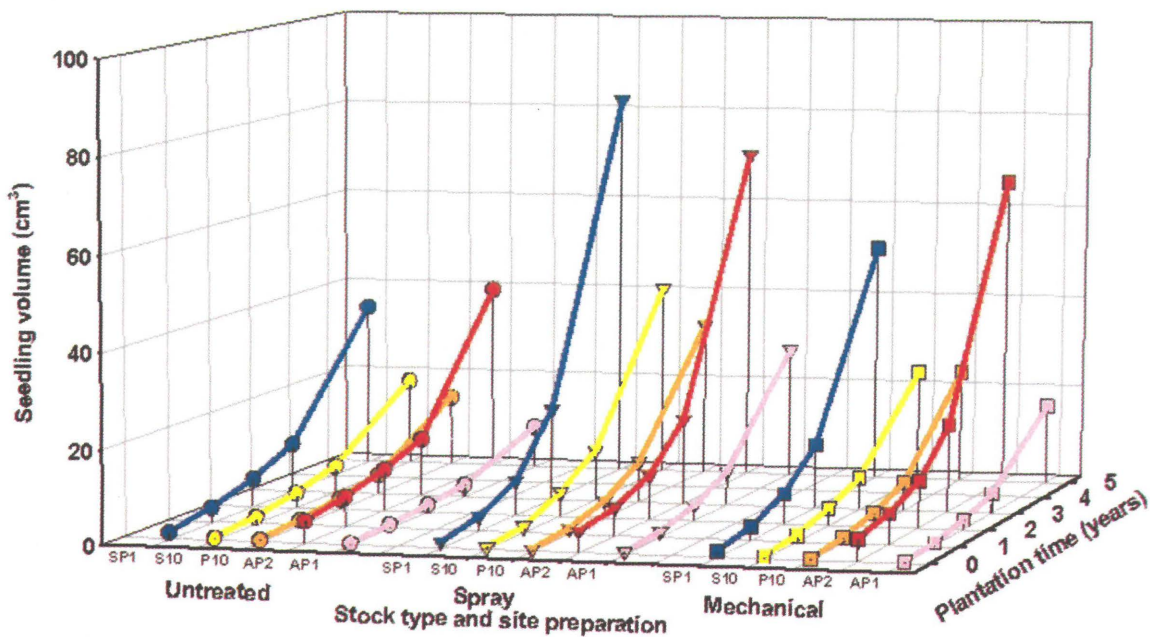


Figure 9. Fort Richardson mature forest development study, site 2, cut 1992 and planted spring 1993.

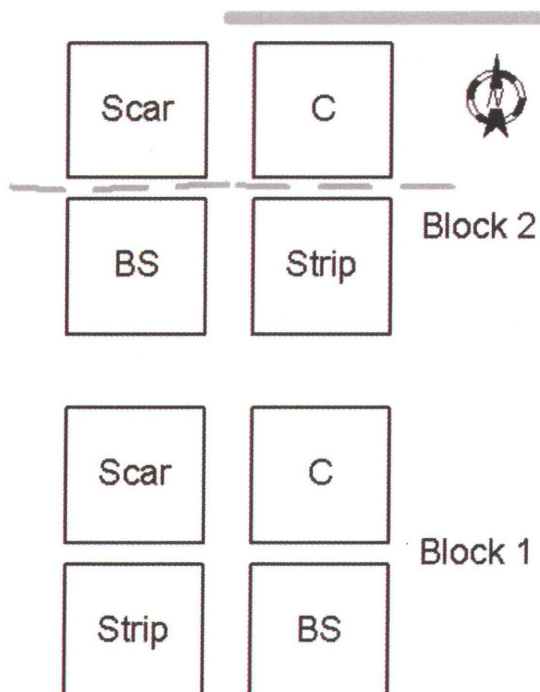


Table 4. Vegetation treatments in the Fort Richardson white spruce mature forest development study.

Treatment	Description
Control	Untreated
Scarified	Mechanical scarification with straight blade to 50% exposure
Strip	Bands sprayed in the spring prior to planting with hexazinone
Broadcast spray	Broadcast sprayed in the fall prior to planting with hexazinone and glyphosate

Table 5. Stock types for the Fort Richardson white spruce mature forest development study.

Stake color	Stock type	Stock description
Blue	Alaska plug	White spruce plug+0; container stock for 1 year, grown at Alaska State Nursery at Eagle River
Orange	Oregon plug	White spruce plug+0; container stock for 1 year, grown at Dean Creek Nursery at Florence, OR
Red	Alaska plug+1	White spruce plug+1; container stock for 1 year, transplanted to raised beds on site for 1 year
Yellow	Willow	Rooted local Bebb willow cuttings, grown 1 year in raised beds on site
Blue	Birch	Rooted paper birch 1.5+0 plugs from Alaska State Nursery at Eagle River from local cuttings

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